Handbook of Corrosion Data

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Preface

The Handbook of Corrosion Data is organized on the basis of environment (chemical compound) rather than along the lines of a specific alloy system. However, the designer or applications engineer is more often faced with choosing an alloy for a specific environment. Therefore, more analysis may be necessary to provide a complete comparison. Books such as the Corrosion Data Survey, 6th Edition, NACE (1985) are an excellent complement to this handbook.

The reader is cautioned that corrosion is indeed a complex subject and that simply looking up the major chemical component in a system may not be sufficient to entirely define the alloys that are suitable for application. In fact, it is far more common that relatively small concentrations of other chemical constituents may be a more controlling factor in the selection of materials than the major component. Thus, it is incumbent on the reader to consider all the chemical species expected in the environment, as well as the effects of temperature, pressure, flow rate, etc. on corrosion. A good resource is the Metals Handbook, Volume 13, published by ASM International, which also includes key references on specific alloys and environments.

The Handbook of Corrosion Data is intended to provide a starting point from which more detailed analysis of the literature may be initiated to dully evaluate the performance of metals in corrosive environments. A book that presents primarily tables and graphs cannot include all of the important support data available in the original paper. Therefore, the original papers must be consulted for important parameters that affect corrosion, such as test duration, solution composition, temperature, stress level, heat treatment, etc. Final selection of metals for a specific environment should be based on more detailed literature surveys and/or testing in the actual or a simulated environment.

The purpose of this book is to provide those involved with the corrosion of metals and alloys a starting point to quickly and easily assess the recent literature on metals in corrosive environments. This handbook is not intended to provide all of the data available in the literature on every environment that exists. For certain environments (i.e. sulfuric acid), a significant amount of work has been performed over the years, such that specific data or graphs have been adopted as classic reference material on the subject. These classic pieces have been included to aid the reader in "coming up to speed" on a specific environment.

Finally, this book is a complement to the corrosion database from ASM International. While the handbook contains some graphical material not included in the database, all of the tabular data are identical. The database compilation was a time consuming, tedious process for which I thank my co-editor, David Anderson. Without his efforts and attention to detail, the database, and therefore this handbook, could not have been produced.

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Denver, Colorado
September, 1994

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Table of Contents

Part I

Corrosion of Metals and Alloys

Corrosion Concepts

This section is not meant to be a detailed review of corrosion principles, rather it will briefly present corrosion terms that are common convention in the field of corrosion science and engineering. For details on corrosion principles the reader is directed to Fontana[1] and H.H. Uhlig[2].

Corrosion is an electrochemical process that results in the degradation of a metal or alloy. It is a coupled reaction between an anode and at least one cathode. Corrosion (oxidation) occurs at the anode while reduction occurs at the cathode. The various ways (forms) that corrosion manifests itself are myriad but can often be reduced to several basic types.

While certain corrosion terms such as pitting or crevice corrosion are generally recognized nomenclature, the organization of these forms into a general classification scheme has taken several approaches. The most widely accepted categorization of corrosion forms was provided by Fontana[1]. More recently Craig and Pohlman[3] have presented another categorization scheme to help emphasize certain important factors that contribute to a group of corrosion types.

Certainly more important than the categorization scheme, for the use of this book, is the considerable variety of terms used for types of corrosion. The use of so many terms in the literature to define one form of corrosion is the result of several factors. Among these are the complexity of corrosion mechanisms and the tendency for some investigators to invoke new names for established phenomenon simply because of a minor variation in the way corrosion is manifested. Probably the greatest variation comes in the areas of stress corrosion cracking/hydrogen damage. As our understanding of both these corrosion phenomena increases, the complexity also increases. Therefore, much of the corrosion community has lumped together these forms along with other mechanisms that entail cracking (i.e., corrosion fatigue and liquid metal embrittlement) into a more general term: environmentally induced or environmentally assisted cracking. However, certain aspects of stress corrosion cracking and hydrogen damage are quite different. Yet much confusion exists in the literature because some authors carelessly interchange the two. Therefore, it is incumbent on the reader of this book to be familiar with the specific types of corrosion that may be expected in a particular environment or for a certain alloy and the multitude of names by which they may be referenced. Rather than resort to a classification system, some of the more common forms of corrosion are defined below to assist the reader.

Uniform/General Corrosion: A form of attack that produced overall uniform wastage of the metal. Often associated with atmospheric corrosion and some high temperature oxidation or sulfidation attack.

Pitting Corrosion: A high localized attack of the metal creating pits of varying depth, width, and number. Pitting may often lead to complete perforation of the metal with little or no general corrosion of the surface.

Crevice Corrosion: Similar to pitting corrosion in its localized nature but associated with crevices. Stainless steels and some nickel-base alloys are particularly susceptible to this form of corrosion.

Intergranular Attack: The preferential corrosion of grain boundaries in a metal caused by prior thermal treatments and related to specific alloy chemistries.

Dealloying: The selective removal of one element (usually the least noble) from an alloy by the corrosive environment. Also referred to as selective leaching or dezincification, denickelification, etc. designating the element removed.

Corrosion Fatigue: The initiation and extension of cracks by the combined action of an alternating stress and a corrosive environment. The introduction of a corrosive environment often eliminates the fatigue limit of a ferrous alloy creating a finite life regardless of stress level.

Galvanic Corrosion: Accelerated corrosion of the least noble metal when coupled to one or more other metals. The more noble metals are protected from corrosion by this action.

Erosion-Corrosion: Many forms of flow assisted corrosion are often included in this term such as cavitation, impingement, and corrosion-erosion. All of these types of attack are the result of accelerated corrosion due to flow of solids, liquids or gases.

Stress Corrosion Cracking: The initiation and propagation of cracks by the combined action of a corrosive environment and a tensile stress. Generally, susceptibility to cracking increases with increasing temperature. Not every alloy cracks in every environment, however, the list of environment/alloy combinations that produce stress corrosion cracking is continually increasing.

Hydrogen Damage: There are numerous forms of damage associated with hydrogen which are contained under the collective term "hydrogen damage." For hydrogen embrittlement and hydrogen stress cracking, a tensile stress and hydrogen atoms are necessary to cause failure. However, contrary to stress corrosion cracking, susceptibility is greatest near room temperature. Other terms and forms are: hydrogen induced cracking, blistering, sulfide stress cracking, hydrogen stress corrosion cracking, hydriding, hydrogen attack. There are many others too numerous to mention.

Although these forms are presented in the context of aqueous corrosion, many of them are also operative at high temperature. High temperature corrosion by oxidation and sulfidation can take the form of uniform attack, pitting, or dealloying to name a few. It is of utmost importance the reader recognize the difference between high temperature corrosion (oxidation) and

aqueous corrosion. The mechanisms are different and therefore, the correct alloy choice for resistance to one environment often is incorrect if applied to another.

For those not familiar with corrosion, it is important to recognize that most corrosion rates are reported as a time averaged weight loss (mils per year, millimeters per year, etc.) that implies a uniform corrosion rate. However, in actual fact, few metals and alloys corrode in a uniform manner rather, highly localized corrosion (pitting, crevice corrosion, etc.) is the rule. Therefore, the corrosion rates reported in this book and most other books are relative and for purposes of comparison between different alloys.

In simple terms, corrosion can be controlled by any of four methods: cathodic protection, coatings, inhibitors and/or alloy changes. While this reference only addresses the last of these, it is important to recognize that the other methods are often used in combination with alloys of lower corrosion resistance to retard or eliminate corrosion. Therefore, simply choosing the most corrosion resistant alloy may not be the most economical choice.

References:

1. M.G. Fontana, *Corrosion Engineering*, McGraw-Hill Book Co., New York, 1986.

2. H.H. Uhlig and R.W. Revie, *Corrosion and Corrosion Control*, J. Wiley and Sons, New York, 1985.

3. *Metals Handbook*, Vol 13, 9th ed., Corrosion, ASM International, Metals Park, OH, 1987, p 79.

Pure Iron

The general corrosion behavior of pure iron is not unlike many other pure metals; that is, in many instances, pure iron has substantially greater corrosion resistance than many of its alloys, including mild steels and unalloyed cast irons. At the same time, pure iron has little or no resistance against attack by such aggressive chemicals as the stronger acids.

Corrosion in Atmospheres

Irons of high purity show a remarkably high resistance to corrosion. They sometimes remain untarnished in laboratory atmospheres for months or even years. Also, pure iron shows a higher resistance to rusting in rural atmospheres as contrasted with its behavior with mild steel. However, in industrial and/or saline atmospheres, uncoated pure iron has very poor resistance to corrosion—perhaps little, if any, more than mild steels. Therefore, any form of iron that is relatively pure—such as wrought iron—should be coated to ensure acceptable life in most atmospheres.

Corrosion in Aqueous Solutions

Under some conditions, pure iron does show unusually good corrosion performance in various types of waters. The degree of resistance is largely governed by two major factors: oxygen content and the pH level of the water. When the oxygen content of the water is exceptionally low (almost none) and when the pH value is above 5, the corrosion rate is almost nil. However, when the pH values are under 4 to 5, there is a rapid increase in corrosion rate, especially at higher oxygen levels.

Like many other metals, pure iron resists corrosion caused by aqueous solutions much better when the surface is completely and continuously immersed, as occurs in pipes and tanks.

Cast Irons

Cast irons are primarily alloys of iron that contain more than 2% carbon and 1% or more silicon. With proper alloying, the corrosion resistance of cast irons can be greatly improved. Thus, this group of materials finds wide application in corrosion-inducing environments. Such service conditions include water, soils, acids, alkalis, saline solutions, organic compounds, sulfur compounds, and liquid metals. Table 1 gives the chemical resistance of cast iron to various materials.

The generally used alloying elements that enhance corrosion resistance include silicon, nickel, chromium, copper, and molybdenum. Less frequently, titanium and vanadium are also used.

Silicon

Silicon is not considered an alloying element in cast iron until it exceeds a level of 3%. Between 3 and 14%, there is some increment of corrosion resistance. Above the 14%, silicon causes the corrosion resistance factor to increase dramatically,

Table 1 Chemical Resistance of Cast Iron to Various Materials

This table was compiled from data supplied by material manufacturers. Their nomenclature was condensed into key symbols: A, acceptable—excellent resistance, fully resistant, suitable, recommended, excellent compatibility, fully compatible; Q, questionable—good resistance, minor effect, moderate effect, slight effect, slight attack, fair resistance; N, not recommended—severe effect, unsatisfactory, not acceptable, do not use. Temperature conditions are outlined in the footnotes.
Source: Oberdorfer Pump Division, Syracuse, NY

Material	Resistance rating
Acetaldehyde(a)	Q
Acetamide	N
Acetate solvents	N
Acetone(a)(c)	A
Acetylene(a)	A
Acetylene tetrabromide	N
Acid, acetic (50% unaerated)(a)	N
Acid, acetic (50% unaerated)(c)	N
Acid, acetic (100% unaerated)(a)	N
Acid, acetic (100% unaerated)(c)	N
Acid, acetic anhydride(a)	A
Acid, acetic anhydride(c)	A
Acid, acetic, vapor	Q
Acid, arsenic(c)	N
Acid, benzene sulfonic	N
Acid, benzoic(a)	N
Acid, boric(c)	N
Acid, butyric(a)	N
Acid, carbolic (phenol)(a)	N
Acid, carbonic	N
Acid, chloroacetic(a)	N
Acid, chlorosulfonic	N
Acid, chromic (5%)(a)	N
Acid, chromic (10%)(c)	N
Acid, chromic (50%)(c)	N
Acid, citric (15%)(a)	N
Acid, citric (15%)(c)	N
Acid, citric (conc.)(c)	N
Acid, cresylic	Q
Acids, fatty	N
Acid, fluoroboric	N
Acid, fluorosilicic	N
Acid, formic(a)(b)	N
Acid, glacial acetic	N
Acid, hydrogromic(c)	N
Acid, hydrochloric (20%)(a)	N
Acid, hydrochloric (37%)(a)	N
Acid, hydrochloric (all)(b)	N
Acid, hydrocyanic	N
Acid, hydrofluoric (up to 50%)	N
Acid, hydrofluoric (50–100%)	N
Acid, lactic (5%)(a)	N
Acid, lactic (5%)(b)	N
Acid, lactic (10%)(b)(c)	N
Acid, nitric (conc.)(a)	N
Acid, nitric (fuming)(a)	N
Acid, oleic (5%)(a)	N
Acid, oxalic (10%)(a)	Q
Acid, phosphoric (crude)	N
Acid, phosphoric (1%)(a)	N
Acid, phosphoric (10%)(a)	N
Acid, phosphoric (50%)	N
Acid, phosphoric (pure)	N
Acid, picric water solution	A
Acid, stearic (conc.)(c)	Q
Acid, sulfuric (5%)(a)	N
Acid, sulfuric (5%)(c)	N
Acid, sulfuric (10%)	N
Acid, sulfuric (30%)(a)	N
Acid, sulfuric (30%)(c)	N
Acid, sulfuric (75%)	N
Acid, sulfuric (conc.)(a)	N
Acid, sulfuric (conc.)(c)	N
Acid, sulfuric (fuming)(a)	N
Acid, sulfurous(b)	N
Acid, tannic (10%)(a)(b)	Q
Acid, tartaric(a)(b)	Q
Acid, trichloroacetic(50%)	N
Acrylonitrile	Q
Alcohol, amyl(a)	A
Alcohol, benzyl	A
Alcohol, butyl(a)	N
Alcohol, diacetone	A
Alcohol, ethyl	A
Alcohol, hexyl	A
Alcohol, isobutyl	Q
Alcohol, isopropyl	Q
Alcohol, methyl	A
Alcohol, octyl	A
Alcohol, propyl	Q
Aluminum chloride (5%)(a)	N
Aluminum hydroxide (sat.)(a)	A
Aluminum oxide	N
Aluminum sulfate (sat.)(a)	N
Amines	N
Ammonia, anhydrous (liquid)(a)	A
Ammonia liquors	A
Ammonia nitrate	A
Ammonium bicarbonate(b)	Q
Ammonium bifluoride	N
Ammonium carbonate(a)(c)	A
Ammonium chloride (50%)(a)(c)	N
Ammonium hydroxide (10%)	A
Ammonium hydroxide (46.5%)	A
Ammonium nitrate(a)	A
Ammonium oxalate(a)	N
Ammonium persulfate (a)	N
Ammonium phosphate	Q
Ammonium sulfate (sat.)(a)(c)	Q
Ammonium thio-sulfate	N
Amyl acetate	Q
Amyl alcohol	A
Aniline (sat.)(a)	Q
Aniline dyes	Q
Aniline oil	A
Anise oil	N
Antifreeze, Dowgard	A
Antifreeze, Hubbard-Hall	A
Antifreeze, Permaguard	A
Antifreeze, Prestone	A
Antifreeze, Pyro-Permanent	A
Antifreeze, Pyro-Super	A
Antifreeze, Shell Zone	A
Antifreeze, Texaco P.T.	A
Antifreeze, Telar	A
Antifreeze, Valvolene	A
Antifreeze, Zerex	A
Aromatic hydrocarbons	A
Asphalt	A
ASTM oils No. 1, No. 2, No. 3	A
Automotive gasoline	A
Aviation gasoline	A
Barbecue sauce	N
Barium chloride (sat.)(a)	Q
Barium hydroxide(a)	A
Barium nitrate(b)	A
Beef extract	N
Beer	N
Beet sugar syrups	A
Benzaldehyde	A
Benzene(a)	A
Benzine (gasoline)	A
Benzol (benzene)(b)	A
Benzyl chloride	N
Borax	A
Boron fuels	N
Brake fluid	A
Brewery slop	A
Brine	N
Butane	A
Butanol (butyl alcohol)	A
Butter	N
Buttermilk	N
Butyl acetate(a)	A
Butyraldehyde	A
Calcium bisulfate	N
Calcium chloride(a)	Q
Calcium hydroxide (10%)(c)	A
Calcium hypochlorite (2%)(a)	N
Calcium hypochlorite (20% on plastics)	N
Calcium sulfate(a)	A
Calgon	N
Cane sugar liquors	A
Carbon dioxide	N
Carbon disulfide	A
Carbon monoxide	N
Carbon tetrachloride	Q
Carbonated beverages	N
Castor oil	A
Catsup	N
Cellulube	A
Chlorinated lime	N
Chlorine (anhydrous liquid)	Q
Chloroacetone	N
Chlorobenzene(a)	N
Chlorobromomethane	N
Chlorobutadiene	N
Chloroform(a)	N
Chlorox (bleach)	N
Chocolate syrup	N
Cider	N
Cinnamon oil	N
Citric oils	N
Clove oil	N
Coconut oil	A
Cod liver oil	N
Copper chloride	N
Copper cyanide (sat.)(c)	N
Copper sulfate (5%)(a)	N
Copper sulfate (sat.)(c)	N
Corn oil	A
Cottonseed oil	A
Cream	N
Creosols	Q
Creosote oil (coal tar)(b)	A
Cutting oil (water-soluble)	A
Cutting oil (sulfur-base)	A
Cyclohexane	A
Developing solutions (hypos)	N
Dibenzyl ether	N
Dibromochloropropane	N
Dibutyl ether	N
Diesel fuel	A
De-ester synthetic lubricants	A
Diphenyl oxides	A
Distillery wort	Q
Ether compounds	Q
Ethyl acetate	A
Ethyl chloride	Q
Ethyl ether	Q
Ethylene chloride	Q
Ethylene dichloride	A
Ethylene glycol	A
Ethylene oxide	N
Fatty acids	Q
Ferric chloride	N
Ferric sulfate	N
Ferrous chloride	N
Ferrous sulfate	N
Fish oil	N
Formaldehyde (Formaline)	Q
Freon 11	Q
Freon 12	A
Freon 22	Q
Fruit juices	N
Furfural	A

Temperature conditions: (a) room ambient, to 100 °F; (b) medium temperature, 100–200 °F; (c) high temperature, >200 °F; if no temperature is listed, use room ambient.

(Continued)

Table 1 (continued)

Material	Resistance rating	Material	Resistance rating	Material	Resistance rating
Gasoline	A	Oil, coconut	A	Sodium bisulfite	N
Gelatin	N	Oil, corn	A	Sodium carbonate	Q
Ginger oil	N	Oil, cottonseed	A	Sodium chloride	A
Glucose	A	Oil, creosote	A	Sodium chromate	A
Glue	A	Oil, diester synthetic lubricating	A	Sodium cyanide	A
Glycerin (glycerol)	A	Oil, Dromus	A	Sodium hydroxide (15%)(a)	A
Gold monocyanide	N	Oil, hydraulic	A	Sodium hydroxide (20%)	A
Grapefruit oil	N	Oil, linseed	A	Sodium hydroxide (50%)(a)	Q
Grape juice	N	Oil, mineral(a)(b)	A	Sodium hypochlorite	N
Grease	A	Oil, olive	A	Sodium metaphosphate	N
Heptane	A	Oil, pale	A	Sodium nitrite	A
Hexane	A	Oil, palm	A	Sodium perborate	Q
Honey	A	Oil, peanut	A	Sodium peroxide(c)	N
Hydraulic fluids	A	Oil, Pella	A	Sodium phosphate mono	N
Hydrazine (water-base)	Q	Oil, pine	Q	Sodium phosphate DI	A
Hydrazine (alcohol-base)	Q	Oil, rapeseed	A	Sodium phosphate TRI	A
Hydrogen peroxide(a)	N	Oil, red	Q	Sodium polyphosphate	A
Hydrogen peroxide(10%)	N	Oil, Royal Triton	A	Sodium silicate	A
Hydrogen sulfide(a)	N	Oil, sesame seed	A	Sodium sulfate (conc.)(a)	A
Ink	N	Oil, Shell Dieselene	A	Sodium sulfide (sat.)(a)	A
Iodine	N	Oil, silicone	A	Sodium sulfite (5%)(a)	A
Isopropyl alcohol	A	Oil, soybean	A	Sodium thiosulfate	Q
Jet fuel (JP1–JP6)	A	Oil, sperm	A	Sodium tripolyphosphate	N
Kerosene	A	Oil, sulfur-base cutting	A	Sorghum	A
Kerosene & naphtha	A	Oil, turbine	A	Soybean oil	A
Lacquers	Q	Oil, vegetable	A	Soy sauce	N
Lard(a)	A	Oil, water-soluble cutting	A	Sperm oil	A
Larvacide	A	Paint (with xylene)	A	Stannic chloride(a)	N
Lime	A	Palm oil	A	Stannic fluoborate	N
Linseed oil	A	Peanut oil	A	Starch	Q
Lithium bromide	A	Perchloroethylene	A	Stoddard solvent	A
Lube oil SAE 10, 20, 30, etc.	A	Phenol (carbolic acid)	N	Sulfate liquors	N
Lubricating oils	A	Photographic developer	N	Sulfur-base cutting oil	A
Magnesium chloride (5%)(a)	N	Pine oil	Q	Sulfur chloride	N
Magnesium hydroxide(a)	A	Pipeline cleaner	A	Sulfur dioxide (dry)	A
Magnesium nitrate	N	Potassium bicarbonate	A	Tetrachloroethane	Q
Magnesium oxide	A	Potassium carbonate(a)	A	Tetraethyl lead	A
Magnesium sulfate (5%)(b)	A	Potassium chloride(a)	A	Thionyl chloride	N
Mayonnaise	N	Potassium chromate	A	Toluene	A
Malamine resins	N	Potassium cyanide	A	Toothpaste	N
Mercuric chloride	N	Potassium dichromate	A	Transformer oil	A
Mercury	A	Potassium hydroxide (5%)(b)	Q	Transmission fluid	A
Methanol	A	Potassium hydroxide (50%)(b)	Q	Trichloroethane	A
Methyl alcohol	A	Potassium hydroxide (50%)(c)	Q	Trichloroethylene	Q
Methyl chloride	A	Potassium permanganate	A	Trichloropane	A
Methylene bromide	A	Potassium phosphate	N	Trichloropropane	A
Methylene chloride	A	Potassium sulfate (5%)(a)	A	Turpentine	A
Milk	N	Potassium sulfate (5%)(b)	A	Urine	A
Mineral oil	A	Propane	A	Varnish	Q
Molasses	A	Propylene glycol	A	Vegetable juices	N
Multicircuit etch	N	Pyridine	A	Vegetable oil	Q
Mustard	N	Rapeseed oil	A	Vinegar(a)	Q
Naphtha	A	Salad dressing	N	Water, tap (to 180 °F)	Q
Naphthalene	A	Sesame seed oil	A	Water, boiling	Q
Nickel chloride(a)	N	Shellac	A	Water, distilled	N
Nickel sulfate(a)	N	Silica gel	A	Water, mine	Q
Nitro benzene	Q	Silicone X527	A	Water, salt(a)	N
Oil, aniline	A	Silver nitrate	N	Whiskey & wines	N
Oil, ASTM No. 1, No. 3	A	Soap solutions(a)	A	White liquor	Q
Oil, bone	A	Soda ash (sodium carbonate)(a)	A	Xylene	A
Oil, castor	A	Sodium arsenite	N	Zinc chloride(a)	N
Oil, Chevron	A	Sodium bicarbonate(b)	Q	Zinc hydrosulfite	N
Oil, citric	N	Sodium bisulfate	N	Zinc sulfate (sat.)	Q

Temperature conditions: (a) room ambient, to 100 °F; (b) medium temperature, 100–200 °F; (c) high temperature, >200 °F; if no temperature is listed, use room ambient.

but at the expense of strength and ductility. A level over 16% makes the alloy brittle and difficult to manufacture.

Alloying with silicon promotes the formation of strongly adherent surface films. However, considerable time may be required to establish these films fully on the castings. Initial corrosion rates may be relatively high for the first few hours, or even days, of exposure. Thereafter, a sharp decline typically occurs until an extremely low, steady-state rate develops. This lasts for the rest of the time the part is exposed to the corrosive environment.

Nickel

Nickel although commonly used to increase the strengthening and hardening qualities of cast irons, also increases corrosion resistance by the formation of protective oxide films on the surfaces of the castings. Up to 4% is added, in combination with

chromium, to improve both corrosion resistance and strength. The resulting enhanced hardness improves erosion-corrosion resistance. Resistance to the effects of acids and alkalis is also improved. Generally, the addition of 12% nickel, or greater, is required to optimize the corrosion resistance level.

Chromium

Chromium may be added to cast irons either by itself or in combination with nickel and/or silicon to increase corrosion resistance. Small additions of chromium are used to refine graphite and matrix microstructures. These refinements improve corrosion resistance in seawater and weak acid environments. Chromium additions between 15 and 30% improve this factor against oxidizing acids such as nitric acid (HNO_3).

Additions of chromium to cast irons create the formation of a protective oxide on the surfaces of the castings. The oxides formed resist oxidizing acids, but they will be of little benefit under reducing conditions. As with silicon additions, higher additions of chromium reduce the ductility of cast iron.

Copper

Copper may be added to cast iron in special cases. Copper additions of 0.25 to 1% increase the resistance of cast iron to dilute acetic (CH_3COOOH), sulfuric (H_2SO_4), and hydrochloric (HCl) acids, as well as to acid mine water. Small additions of copper of up to 10% are made to some high-nickel/chromium cast irons to increase corrosion resistance.

Molybdenum

Molybdenum is added to cast irons to increase strength; however, it may also be added to increase corrosion resistance, particularly in high-silicon cast irons. The addition of molybdenum is particularly useful in HCl. As little as 1% is helpful in some high-silicon irons, but for optimum resistance, between 3 and 4% molybdenum is added.

Forms of Corrosion

Cast irons exhibit the same forms of corrosion as other metals and alloys. These include:

- Galvanic corrosion
- Crevice corrosion
- Pitting
- Intergranular corrosion
- Selective leaching
- Erosion-corrosion
- Stress-corrosion
- Corrosion fatigue
- Fretting corrosion

Coatings

Four general categories of coatings are used on cast irons to enhance corrosion resistance. These are metallic, organic, conversion, and enamel coatings. Coatings on cast irons are generally used to enhance the corrosion resistance of unalloyed and low-alloy cast irons. High-alloy cast irons are rarely coated.

Selection

When properly matched for the service environment for which they are intended, cast irons can provide excellent resistance to a wide range of corrosion environments. The basic parameters to consider before selecting an individual type are:

- Concentration of solution components
- Contaminants, even at ppm levels pH of solution
- Temperature range and rate of change
- Degree of aeration
- Percent and type of solids
- Continuous or intermittent operation
- Upset potential: maximum temperature and concentration
- Unusual conditions, such as high velocity and vacuum
- Materials currently used in the system and potential for galvanic corrosion

Carbon Steels

Carbon steel is the most widely used engineering material in the United States. For example, it accounted for approximately 88% of the tonnage in 1984 and 1985. Despite its relatively limited corrosion resistance, very large amounts of carbon steel are used in marine applications, nuclear and fossil fuel power plants, transportation, chemical processing, mining, construc-

tion, and metal-processing equipment. All of these areas present unique corrosion problems. Table 2 gives the corrosion resistance of carbon steel to various environments.

Two very valuable generalizations can be made concerning the corrosion of carbon steels. First, when solving a particular corrosion problem, a dramatic change in attack rate can often be achieved by altering the corrosive environment. For example, in the area of aqueous corrosion, deaeration of water and the addition of corrosion inhibitors effect significant changes. Second, when dealing with carbon steels, the alteration of design factors is a very effective means of minimizing corrosion. Both of these techniques are preferable to simply changing the grade of steel.

Definition

The term "carbon steel" is often loosely used and therefore may be misunderstood. It does not necessarily imply that the steel does not contain alloying elements, which it may. There are, however, sharp restrictions on the amounts of alloys that may be used in the material and still have it qualify as a carbon steel. By their nature, carbon steels have a very limited alloy content, usually less than 2 wt% of the total additions. Unfortunately, these levels of alloying additions do not produce any remarkable changes in general corrosion behavior.

For steel to be considered a carbon steel, it is generally agreed that one or more of the following conditions exists:

- No more than 1 wt% carbon can be included.
- No minimum content is specified or required for aluminum (except as related to deoxidation or grain-size control), chromium, cobalt, niobium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other element added to obtain a desired alloying effect.
- The specified *minimum* copper content does not exceed 0.40 wt%.
- The *maximum* content specified for any of the following elements does not exceed 1.65% manganese, 0.06% silicon, or 0.60% copper.

Boron may be added to improve hardenability without changing the status of a carbon steel. In all carbon steels, small quantities of alloying elements—such as nickel, chromium, and molybdenum—are likely to be present. Their existence is unavoidable, because they are retained from raw materials used in melting. As a rule, these minor amounts have little or no effect on the end use of the material.

Table 2 Corrosion Resistance of Carbon Steel to Various Environments

E, excellent—virtually unattacked under all conditions; G, good—generally acceptable with a few limitations; S, satisfactory—suitable under many conditions, not recommended for the remainder (consult a steel manufacturer for details); P, poor—unsuitable under all conditions
Source: The Duriron Company, Inc., Dayton, OH

Environment	Resistance rating	Environment	Resistance rating	Environment	Resistance rating	Environment	Resistance rating
Acetate solvents	S	Carbon tetrachloride	S	Lead sulfide	P	Sodium bisulfate	P
Acetic acid, all strengths	P	Cellulose acetate	S	Lithophone	S	Sodium bisulfite	S
Acetic anhydride	P	Chloroacetic acid	P	Magnesium chloride	S	Sodium chlorate	P
Alum	P	Chlorinated water	P	Magnesium sulfate	S	Sodium chloride	S
Aluminum chloride	P	Chlorine dioxide	P	Maleic acid	S	Sodium ferricyanide	S
Aluminum sulfate & H_2SO_4	P	Chlorine gas, wet	P	Malic acid	P	Sodium hydroxide	S
Ammonium chloride	P	Chromic acid	P	Manganese chloride	S	Sodium hydroxide, fused	P
Ammonium fluoride	P	Citric acid	P	Mercuric chloride	P	Sodium hypochlorite	P
Ammonium hydroxide	S	Copper nitrate	P	Mercuric nitrate	P	Sodium nitrate	S
Ammonium nitrate	S	Copper silver nitrate	P	Mercuric sulfate	P	Sodium perchlorate	P
Ammonium phosphate	P	Copper sulfate	P	Mercurous sulfate	P	Sodium phosphate	G
Ammonium sulfate	S	Copper sulfate + 10% H_2SO_4	P	Metal plating solutions	P	Sodium sulfate	S
Ammonium sulfate & H_2SO_4	P	Cupric chloride	P	Mine water	P	Sodium sulfide	P
Aniline dyes	S	Cuprous chloride	P	Mixed acid	P	Sodium sulfite	P
Aniline hydrochloride	P	Ethylene dichloride	P	Nickel chloride	P	Sodium thiosulfate	P
Anodizing solutions	P	Fatty acids	S	Nickel ammonium sulfate	P	Stannic chloride	P
Antimony trichloride	P	Ferric chloride	P	Nitric acid, all strengths	P	Stannous chloride	P
Arsenic acid	P	Ferric ferro-cyanide	P	Nitric acid + 3–5% HF	P	Stearic acid	S
Barium chloride	S	Ferric nitrate	P	Nitrobenzene	S	Sulfite liquors	S
Barium nitrate	S	Ferric sulfate	P	Oleic acid	S	Sulfite liquors + H_2SO_4	P
Barium sulfate	S	Ferric sulfate + 10% H_2SO_4	P	Oleum	S	Sulfur	S
Benzoic acid	P	Ferrous sulfate	P	Oxalic acid	P	Sulfur chloride	P
Black liquor	P	Ferrous sulfate + 10% H_2SO_4	P	Phenol	S	Sulfur dioxide	S
Boric acid	P	Formaldehyde	P	Phosphoric acid + 2% H_2SO_4 1% HF	P	Sulfuric acid, sat. with SO_2	P
Brine, acid	P	Formic acid	P	Phosphoric acid, all strengths	P	Sulfuric acid, up to 100 °F	P
Brine, alkaline	G	Glycerin, crude	P	Picric acid	P	Sulfuric acid, 5% to boiling	P
Bromine, dry	P	HCL waste pickel liquor	P	Phthalic acid	S	Sulfuric acid, 60–100% 176 °F	P
Bromine, wet	P	Hydrochloric acid (<150 °F)	P	Potassium bisulfate	P	Sulfurous acid	P
Cadmium sulfate	S	Hydrochloric acid (>150 °F)	P	Potassium chloride	S	Sugar solutions	S
Calcium bisulfate	P	Hydrofluoric acid	P	Potassium hydroxide	S	Tannic acid	P
Calcium bisulfite & H_2SO_4	P	Hydrofluosilicic acid	P	Potassium iodide	S	Tar and ammonia	S
Calcium chloride	S	Hydrogen peroxide	S	Potassium nitrate	S	Tartaric acid	P
Calcium hydroxide (lime)	S	Hypochlorite bleach	P	Potassium sulfate	S	Titanic sulfate	P
Calcium hypochlorite	P	Iodine, dry	S	Pyridine sulfate	S	Toluene	S
Calcium phosphate	S	Lactic acid	P	Sea water	S	Zinc chloride	P
Carbon bisulfide	P	Lead acetate	P	Sodium bicarbonate	S	Zinc sulfate	P
Carbonic acid	P	Lead nitrate	P	Sodium bichromate	G		

Classification

Carbon steels are arbitrarily divided into three groups according to carbon content. The low-carbon group (commonly referred to as "mild" steels) contains 0.08 to 0.28% carbon. The "medium" group usually contains 0.28 to 0.55% carbon. The "high carbon" group contains 0.50 to 1.0% carbon.

Corrosion Service

As a rule, only the low-carbon (mild) steels are in any way considered for resistance to corrosion. They are generally more corrosion resistant than the medium- and high-carbon groups. More importantly, they are more amenable to welding and forming, a common requirement for building structures of a variety of types.

Without some sort of surface protection, carbon steels are hardly worth considering for resisting attack by very aggressive chemicals, simply because this kind of attack is so very rapid. However, carbon steel in vast quantities has been successfully used in conditions of severe atmospheric and water attack, much of it severe.

The two conditions necessary to initiate corrosion of low-carbon steel within natural environments are water and oxygen. After these essentials, there are a number of variables that affect the corrosion process. For example, samples of mild steels that are wholly immersed corrode faster if uninhibited water is moving around them than if the water is stagnant, but less rapidly where velocity is high if an inhibitor is present. Another of the many variables is the process called "cycling." Water pipes and tanks corrode much more slowly if the immersed surface remains completely submerged as opposed to alternating between submersion and partial or total exposure.

Carbon steels perform well in dry, rural atmospheres, but the rate of corrosion increases quickly in high-humidity saline or industrial atmospheres. The useful service life of carbon steels has been recorded for boiler service of up to 25 years where the conditions are controlled. It is thus obvious that stainless steels, copper-base alloys, and other highly corrosion-resistant alloys are not always required for many such applications.

Corrosive Environments. There are a number of major corrosive conditions into which carbon steels can be successfully introduced. These include:

- Atmospheric corrosion, including humidity, and both natural and man-made pollutants
- Soil corrosion, as determined by such factors as moisture content, level of electrical conductivity, acidity level, amount of dissolved salts, and aeration
- Corrosion in concrete, as caused primarily by chloride ions, and most successfully combated by cathodic protection
- Boiler service, which is a specialized form of aqueous corrosion that also involves elevated temperatures
- Liquid-metal corrosion, which may result in either dissolution and saturation of the liquid metal, or in the formation of intermetallic alloys of the steel with the liquid metal

Coatings (usually paint) can make carbon steels highly resistant to the most aggressive environments. Common examples include buildings, bridges, and ships. The types of coatings available range from oiling for low-cost, temporary protection to vapor deposition for long-term corrosion, heat, and wear resistance. For economic reasons, the desired degree of protection must be determined before a specific coating is selected.

Low-Alloy Steels

There is widespread inconsistency regarding the use of the term "alloy steel." The terms "low-alloy steel" and "alloy steel" are often used ambiguously. For the purposes of this Handbook, an alloy steel is defined as a steel containing significant quantities of alloying elements (other than carbon and the commonly accepted amounts of manganese, silicon, sulfur, and phosphorus added to effect changes in the mechanical or physical properties. The definition could, of course, include stainless steels and iron-base superalloys.

The American Iron and Steel Institute, in conjunction with the Society of Automotive Engineers, offers a more detailed and restrictive definition. A steel is considered to be an alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: (a) 1.65% manganese, (b) 0.60% silicon, and (c) 0.60% copper. It is considered an alloy steel when a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized constructional alloy steels: aluminum, chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium, zirconium, or any other element added to obtain a specific alloying effect. As a rule, the total amount of alloy in the AISI-SAE grades designated as "alloy steels" does not exceed approximately 4.0% over and above that permitted in carbon steels.

Classification

For the present purposes, steels have been divided into low-alloy steels, those steels with approximately 5% or less total alloying, and alloy steels, those steels with more than 5% alloying elements but not sufficient alloying to enter the

stainless steel categories. Although this may not be a universally recognized categorization, it does emphasize the importance of low-alloy steels.

Corrosion Service

It is well recognized that the primary purpose of low-alloy steels is to achieve improved mechanical properties and fracture toughness than can be obtained with carbon steels. In general, the small amount of alloying in low-alloy steels is not sufficient to impart any appreciable corrosion resistance. That is, in fairly corrosive or aggressive environments, alloying up to 5% is not adequate to provide substantial corrosion resistance. However, in less severe environments, such as atmospheric corrosion, small additives of copper, phosphorus, chromium and nickel provide significant improvement in atmospheric corrosion resistance compared to carbon steel.

Copper is especially effective. Data have shown that the presence of no more than 0.6% copper greatly extends the service life of steels in industrial atmospheres. In marine atmospheres, where plain, low-carbon steel showed a weight loss of 43 mg/dm^2 in a specific period of time, steels with additions of 1.03% copper and 0.06% chromium reduced the rate to 17.3 mg/dm^2. Furthermore, for steels containing 1.19% chromium and 0.46% copper, the corrosion rate dropped to 6.3 mg/dm2. It is obvious then that even relatively small amounts of alloying additions can prolong the service life of steel structures in atmospheric exposure.

In aqueous solutions, low-alloy steels behave essentially the same as carbon steels. Thus, their resistance to various forms of corrosion (i.e., pitting, crevice corrosion, etc.) is similar. However, low-alloy steels are frequently used at much higher strength levels than carbon steels, thus the commonly used phrase high-strength low-alloy steels (HSLA). These applications, by virtue of the need for higher strength, have a tendency to create a greater susceptibility of low-alloy steels to hydrogen damage (embrittlement) and stress-corrosion cracking. Likewise, the resistance to corrosion fatigue of high-strength low-alloy steels may be diminished in corrosive environments more so than carbon steels. This sensitivity to environmentally assisted cracking has produced a large number of papers dealing with this problem, and therefore, the literature is especially focused on this issue.

Besides the many standardized low-alloy steels (AISI, ASTM, etc.), there are numerous proprietary and special-purpose low-alloy steels in the marketplace that find wide application.

Alloy Steels

The term "alloy steels" describes those steels with more than 5% alloying elements, but less than the typical 11% chromium level that constitutes the beginning of the stainless steel family of alloys. Prominent among alloy steels are two systems: one that has increasing chromium contents from essentially 5 up to 9% Cr and the other that emphasizes nickel with a range of approximately 4 to 9% Ni. The former group is used primarily for increased resistance to oxidation at elevated temperatures. The latter group is commonly used for improved fracture toughness down to cryogenic temperatures.

Corrosion Service

Although both of these series (Cr and Ni) have been used in aqueous environments in several industries, they have met with limited success. In fact, alloy steels are not typically considered for corrosion resistance. The limited corrosion resistance gained at the cost of alloying is not easily justified. Therefore, most designers and corrosion engineers prefer to use either low-alloy steels that are protected by coatings or inhibitors, or to significantly increase alloy content to achieve a stainless steel or iron-base superalloy that possesses inherent corrosion resistance. Because of the limited corrosion resistance of these alloys, the literature does not contain a great deal of information; likewise research activity on the corrosion resistance of these alloys is limited.

As with the low-alloy steels, there are numerous proprietary and special-purpose alloy steels that are similar to the standard chromium and nickel steels in their corrosion resistance.

Stainless Steels

Stainless steels are iron-base alloys containing at least 12% chromium. Maximum corrosion protection occurs, generally, with the highest chromium content, which may range up to about 30%. Corrosion resistance of stainless steels is a function not only of composition, but also of heat treatment, surface condition, and fabrication procedures, all of which may change the thermodynamic activity of the surface and thus dramatically affect the corrosion resistance. Table 3 gives the relative corrosion resistance of AISI stainless steels.

Table 3 Relative Corrosion Resistance of AISI Stainless Steels

The "X" notations indicate that a specific stainless steel type may be considered as resistant to the corrosive environment categories.
Source: Steel Products Manual "Stainless and Heat Resisting Steels," American Iron and Steel Institute, Washington, DC, Dec 1974

Type No.	UNS No.	Mild atmospheric and fresh water	Atmospheric		Salt water	Chemical		
			Industrial	Marine		Mild	Oxidizing	Reducing
201	S20100	X	X	X		X	X	
202	S20200	X	X	X		X	X	
205	S20500	X	X	X		X	X	
301	S30100	X	X	X		X	X	
302	S30200	X	X	X		X	X	
302B	S30215	X	X	X		X	X	
303	S30300	X	X			X		
303 Se	S30323	X	X			X		
304	S30400	X	X	X		X	X	
304L	S30403	X	X	X		X	X	
	S30430	X	X	X		X	X	
304N	S30451	X	X	X		X	X	
305	S30500	X	X	X		X	X	
308	S30800	X	X	X		X	X	
309	S30900	X	X	X		X	X	
309S	S30908	X	X	X		X	X	
310	S31000	X	X	X		X	X	
310S	S31008	X	X	X		X	X	
314	S31400	X	X	X		X	X	
316	S31600	X	X	X	X	X	X	X
316F	S31620	X	X	X	X	X	X	X
316L	S31603	X	X	X	X	X	X	X
316N	S31651	X	X	X	X	X	X	X
317	S31700	X	X	X	X	X	X	X
317L	S31703	X	X	X	X	X	X	
321	S32100	X	X	X		X	X	
329	S32900	X	X	X	X	X	X	X
330	N08330	X	X	X	X	X	X	X
347	S34700	X	X	X		X	X	
348	S34800	X	X	X		X	X	
384	S38400	X	X	X		X	X	
403	S40300	X				X		
405	S40500	X				X		
409	S40900	X				X		
410	S41000	X				X		
414	S41400	X				X		
416	S41600	X						
416 Se	S41623	X						
420	S42000	X						
420F	S42020	X						
422	S42200	X						
429	S42900	X	X			X	X	
430	S43000	X	X			X	X	
430F	S43020	X	X			X		
430F Se	S43023	X	X			X		
431	S43100	X	X	X		X		
434	S43400	X	X	X		X	X	
436	S43600	X	X	X		X	X	
440A	S44002	X				X		
440B	S44003	X						
440C	S44004	X						
442	S44200	X	X			X	X	
446	S44600	X	X	X		X	X	
	S13800	X	X			X	X	
	S15500	X	X	X		X	X	
	S17400	X	X	X		X	X	
	S17700	X	X	X		X	X	

Stainless steels are used in a wide variety of corrosion-resistant applications. Resistance to tarnish has permitted architectural applications and automobile trim use. Stainless is used for its resistance to foodstuffs and is found in cutlery, flatware, pots and pans, and commercial food-handling equipment. The corrosion environment for the latter applications requires excellent resistance to pitting and crevice corrosion. Where resistance to stress-corrosion cracking may be required in heat-transfer applications, such as steam jacketing for cooking or processing vessels, stainless can be successfully applied.

Iron is not normally an inert element; in most atmospheric or aqueous conditions, iron will corrode. Stainless steels are effectively inert to "aqueous" corrosive environments by virtue of the passivity conveyed by the chromium in solution in iron. They are also very resistant to "dry" corrosion in oxidizing conditions.

Although marine environments can be severe, stainless steels often can provide good resistance. In fresh water, stainless steels have provided excellent service for such items as valve

parts and fasteners, as well as pump shafts in water and wastewater treatment plants. Obviously, the precise type of stainless for each application will need to be determined from the many available. Many factors enter into the successful use of stainless steel in demanding corrosion conditions; water velocity, aeration, water purity, and temperature are several that must be considered. Stress-corrosion cracking, pitting, and crevice corrosion of stainless steels may be especially temperature sensitive.

Stainless steels have good applicability in mineral acids, but resistance depends on the concentration of the hydrogen ions and the oxidizing capacity of the acid, as well as the usual variables associated with composition and processing history. In general, application of stainless in chemical environments requires consideration of all forms of corrosion, along with impurity levels in the stainless and the impurity and degree of aeration of the environment. When an alloy with sufficient general corrosion resistance has been selected, care must be taken to ensure that the material will not fail by pitting or crevice corrosion or by stress-corrosion cracking.

Organic acids are generally less aggressive than mineral acids, but they can be corrosive to stainless, especially when impurities are present. The presence of oxidizing agents, in the absence of chlorides, can reduce corrosion rates. All stainless steels resist general corrosion by sodium hydroxide at temperatures below about 66 °C (150 °F). Stress-corrosion cracking of some stainless steels can occur at higher temperatures. Stainless steels also are highly resistant to most neutral or alkaline nonhalide salts. Halogen salts are more corrosive to stainless, because of the tendency to cause local film failure and pitting. Pitting is promoted in aerated or mildly acidic oxidizing solutions. Chlorides generally are more aggressive than the other halides in causing pitting.

At lower temperatures, most austenitic stainless steels resist chlorine or fluorine gas if the gas is completely dry. The presence of even small amounts of moisture results in accelerated attack, especially pitting or, possibly, stress-corrosion cracking. At higher temperatures, in air or in strong oxidizing environments, stainless is highly resistant to oxidation. However, increased attack can occur if sulfur vapor or sulfur compounds are present in the gas.

At high temperatures, in gaseous oxidation, stainless steels are protected principally by the chrome oxide film produced by interaction of oxygen with chromium in the substrate. At lower temperatures, the passivity of a stainless steel is explained through the formation of a protective film on the surface of the metal. This film will form naturally in oxidizing environments, but it will not reform if degraded in a reducing environment. Some stainless compositions are better suited for reducing environments than others. In general, the stainless steel behavior described below is associated with wrought alloy products. Stainless steel castings usually exhibit comparable corrosion resistance to their wrought counterparts and will not be discussed separately.

It is not necessary to chemically treat stainless steels to achieve passivity. The passive film forms spontaneously in the presence of oxygen. Most frequently, when steels are treated to improve passivity (passivation treatment), surface contaminants are removed by pickling to allow the passive film to reform in air, which it does almost immediately.

The principal alloying elements that affect the corrosion resistance of stainless are discussed below.

Chromium

The one element essential in forming the passive film or high-temperature, corrosion-resistant chrome oxide is chromium. Other elements can influence the effectiveness of chromium in forming or maintaining the film, but no other element can, by itself, create the stainless characteristics of stainless steel. The passive film is observed at about 10.5% chromium, but it affords only limited atmospheric protection at this point. As chromium content is increased, the corrosion protection increases. When the chromium level reaches the 25 to 30% level, the passivity of the protective film is very high, and the high-temperature oxidation resistance is maximized. Because high chromium content may produce problems in fabricability or alloy stability, it is better to enhance the corrosion resistance of stainless with additional alloying elements.

Nickel

In sufficient quantities, nickel is used to stabilize the austenitic form of iron and so produce austenitic stainless steels. A corrosion benefit is obtained as well, because nickel is effective in promoting repassivation, especially in reducing environments. Nickel is particularly useful in promoting increased resistance to mineral acids. When nickel is increased to about 8 to 10%—a level required to ensure austenitic structures in a stainless which has about 18% chromium-resistance to stress-corrosion cracking is decreased. However, when nickel is increased beyond that level, resistance to stress-corrosion cracking increases with increasing nickel content.

Manganese

An alternative austenite stabilizer is sometimes present in the form of manganese, which in combination with lower amounts of nickel than otherwise required will perform many of the same functions of nickel in solution. The effects of manganese on corrosion are not well documented; it is known that manganese combines with sulfur to form sulfides. The morphology and composition of these sulfides can have substantial effects on the corrosion resistance of stainless steels, especially their resistance to pitting corrosion.

Other Elements

Molybdenum in moderate amounts in combination with chromium is very effective in terms of stabilizing the passive film in the presence of chlorides. Molybdenum is especially effective in enhancing the resistance to pitting and crevice corrosion. Carbon does not seem to play an intrinsic role in the corrosion characteristics of stainless, but it has an important role by virtue of the tendency of carbide formation to cause matrix or grain boundary composition changes that may lead

to reduced corrosion resistance. Nitrogen is beneficial to austenitic stainless in that it enhances pitting resistance, retards formation of sigma phase, and may help to reduce the segregation of chromium and molybdenum in duplex stainless steels.

Forms of Corrosion

The various forms of corrosion attack likely to be found in stainless steels are:

- General corrosion
- Galvanic corrosion
- Pitting corrosion
- Crevice corrosion
- Intergranular corrosion
- Stress-corrosion cracking
- Erosion-corrosion

Stainless steels are susceptible to several forms of localized corrosion attack such as intergranular, crevice, or pitting corrosion. The avoidance of this localized attack is the major effort in selecting a steel for a given application, assuming that strength and other properties are acceptable.

Improper heat treatment can produce detrimental results in stainless steels due to changes in the microstructure. The most troublesome problems are caused by carbide precipitation (sensitization) and by the precipitation of intermetallic phases such as sigma. Sensitization can occur when austenitic stainless steels are heated for a period of time in the range 425 to 870 °C (800 to 1600 °F). Time at temperature and the nature of the carbide precipitation greatly affects the corrosion performance. When the carbide precipitation is at the grain boundaries, the reduction in the local chromium content caused by the precipitation of chromium-rich carbides can affect the passivity of the grain boundary area. The effect is called sensitization. Subsequently, in sensitized alloys, dissolution of the low-chromium area or envelope surrounding each grain leads to intergranular corrosion. Sensitization also lowers resistance to other forms of corrosion such as pitting, crevice corrosion, and stress-corrosion cracking.

Sensitization is best avoided by minimizing the time spent in the critical temperature region, because longer times lead to greater degrees of sensitization. Alternate solutions, which generally are more costly, include reduction of carbon content to very low levels to preclude carbide precipitation, increasing the chromium content after carbide precipitation, or addition of strong carbide formers, most notably titanium or niobium, to tie up the carbon so that it will not form chromium carbides. The latter stainless steels are known as "stabilized" stainless.

It should be recognized that sensitization is not only confined to the intergranular corrosion produced in "aqueous" media. Use of a sensitized stainless at elevated temperatures also may result in grain boundary attack (intergranular oxidation), which can seriously affect alloy performance.

If a steel should be sensitized, annealing is the only way to restore the inherent corrosion resistance of the material. Full dissolution of the chromium carbides at temperature is necessary so that the chromium may be homogeneously redistributed within the matrix where it acts to produce corrosion resistance. Controlled cooling will be needed to ensure that the stainless is not sensitized again on its return to room temperature. This latter point is important, because sensitization problems continue to occur in industry on a regular basis when proper cooling procedures are not followed during heat treatment or other processing operations such as welding.

Sigma phase can form by precipitation during heat treatment or during service exposure. Its formation can render stainless steels susceptible to intergranular corrosion. It generally occurs in higher alloyed stainless steels and forms most rapidly at temperatures of about 650 to 925 °C (1200 to 1700 °F). Time spent in this temperature region can be critical to the formation of sigma phase. As in the case of sensitization, the detrimental effects of sigma phase formation may be negated by annealing. Although limited information is available on other phase precipitation, it should be clear that any precipitate that extracts important corrosion-resisting elements from solution (or produces a phase that is more anodic or cathodic to the matrix) has the potential to reduce the corrosion resistance of a stainless steel.

Duplex stainless steels, so called because of their combined ferritic/austenitic microstructure, are finding wide use in many industries. First-generation duplex stainless steels (AISI 329) were prone to the segregation of chromium and molybdenum between the ferrite and austenitic phases on solidification after welding, often with significant degradation of the corrosion resistance of the alloy. The addition of nitrogen to such steels has resulted in better phase composition balance and minimal chromium and molybdenum segregation during welding. The newer duplex grades, therefore, have high corrosion resistance and good resistance to stress-corrosion cracking.

Ferritic stainless steels are virtually immune to stress-corrosion cracking. However, stress-corrosion cracking has been observed in all categories of stainless steels. The stress-corrosion cracking behavior of stainless can be summarized as follows:

- An incubation period is needed before cracking occurs.
- Dissolved oxygen aggravates the conditions.
- Low pH solutions are more aggressive than high pH solutions.
- A minimum or threshold stress is required.
- Cracking may be transgranular or intergranular.

- Susceptibility to cracking is influenced by nickel.
- Cracking tendency increases with increasing yield strength and temperature.

Selection of Stainless Steels for Corrosion Resistance

The topic of selection of stainless steels for corrosion resistance is too extensive to be covered in these general comments. One point to remember is that stainless steels will cost more than copper-base alloys, yet they should cost less than nickel- or titanium-base alloys and thus may well be cost effective for a desired application.

Austenitic Stainless Steels

As a group, the austenitic stainless steels have greater corrosion resistance than the martensitic, ferritic, or precipitation-hardening groups. At the same time, there is a wide range of variations with respect to corrosion resistance among the austenitic types. For the sake of discussion, the austenitic alloys can be divided into four classes — A, B, C, and D. Although imprecise and somewhat arbitrary, this breakdown can serve as a guide for selection based on corrosion resistance.

Class A. AISI types 301, 302, 303, 303Se, 304, 304L, 304N, 321, 347, and 348 are all contained within class A. If minor modifications are acknowledged, each of the types in this group can be considered a so-called 18-8 stainless.

Within class A, there is no great difference in the general corrosion resistance of the individual types. Those that have a higher alloy content are slightly better than those with a lower alloy content. For example, type 304 is slightly superior to types 301 and 302, although types 304 and 304L were initially developed for fabricability. As a rule, the free-machining grade type 303 is the least corrosion resistant of the types just mentioned, and it is especially susceptible to pitting corrosion.

Types 321, 347, and 348 are carbide stabilized with titanium and/or niobium. Although their general corrosion resistance may be no higher than types 302 or 304, they are essentially immune to sensitization.

Class B. Only two AISI types are contained in class B—305 and 384. These have relatively high nickel contents (12.0 and 15.0) nominally and respectively. While they both have greater corrosion resistance than the 18-8 steels, they were actually designed for extra-deep drawing and cold heading operations, as allowed by the higher nickel content.

Class C. AISI types 302B, 308, 309, 309S, 310, 310S, and 314 make up the class C group within the austenitic stainless steels.

Type 302B is a modified 18-8 and has a silicon addition (2.5%) that increases oxidation resistance at elevated temperature.

Type 314 represents a higher alloy version (25-20) of an 18-8. It has a silicon addition that is more corrosion resisting, especially to sulfuric acid, than type 302B. It also has high resistance to scaling at elevated temperatures.

Types 308, 309, 309S, 310, and 310S are all higher in chromium and nickel, and they are commonly called 20-11 (308), 24-12 (309, 309S), and 25-20 (310-310S). They have a very high resistance to corrosion and oxidation at elevated temperature.

Class D. AISI types 316, 316L, 316F, 316N, 317, and 317L make up the class D grouping. The general corrosion resistance of the "316-317 family" is considered equal to type 310, although there are differences. The 316-317 types are far more resistant to certain specific types of corrosion, notably pitting.

Martensitic Stainless Steels

The AISI types that make up the martensitic stainless group are 403, 410, 414, 416, 416Se, 420, 420F, 431, 440A, 440B, 440C. All of the martensitic group, although they do meet the minimum corrosion-resistant requirement for a stainless steel, do not in fact rate as high as the ferritic or austenitic grades relative to this quality.

Types 403, 410, 416, and 416Se. Known as "turbine quality," type 403 is virtually identical to type 410, except that it is made from specially processed and rigorously inspected ingots, as required by steam turbine blades. Both types contain just enough chromium to maintain "stainlessness" (nominally 12.5%), but there are no significant amounts of other alloying elements.

Types 416 and 416Se are simply 410 with the addition of free-machining additives. Although offering improved machining characteristics, there is a sacrifice in corrosion resistance.

Types 414 and 431. These stainless steels provide better corrosion resistance than type 410, largely because they contain a nominal amount (2.0%) of nickel. These steels have been well known as 12-2 and 16-2, respectively. Type 431, with 16.0% chromium, ranks highest in the martensitic category with respect to corrosion resistance.

Types 420 and 420F. Despite a higher chromium content, type 420 does not have an appreciably higher corrosion resistance level than type 410. Type 420F is almost identical to type 420, except that there is an addition of sulfur to improve machinability. This results in a slight sacrifice of corrosion resistance.

Type 422. This is another "12-chrome" grade, but with additions to improve high-temperature strength, required by the common elevated service temperatures.

Types 440A, 440B, and 440C.

These are all high-carbon stainless steels and are sometimes called "stainless tool steels." These types have the highest chromium range of any of the martensitic types, yet their corrosion resistance levels are among the lowest because of their higher chromium content. There is a gradual decrease in

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corrosion resistance from the A to C subtypes. This is also due to the increase in carbon content.

Ferritic Stainless Steels

The AISI types that make up the ferritic stainless steel group are 405, 409, 429, 430, 430F, 430SeF, 434, 436, 442, and 446. As a group, the ferritic stainless steel AISI types do not closely approach the austenitic types with respect to corrosion resistance. There are, however, *some* ferritic types that may nearly equal the corrosion resistance levels of the austenitics in *some* environments, but these are exceptions. At the same time, all of the ferritic types meet the minimum requirements for a stainless steel, which is to say that they remain unattacked in an out-of-doors, unprotected, rural atmosphere.

Type 405. While meeting the minimum requirements for a stainless steel, type 405 is actually relatively low in its resistance to corrosion. The carbon level is 0.08% maximum, and it has a nominal chromium content of 12.5%. An addition of 0.10 to 0.30% aluminum (a powerful ferritizer) prevents the formation of any appreciable amount of austenite at any temperature. It is thus the ideal grade for welding. Because of its low cost and good dimensional stability, the alloy is used principally as a lining for pressure vessels.

Type 409. Of all the stainless steels, type 409 is generally considered to have the lowest degree of corrosion resistance. It contains very nearly the minimum amount of chromium to qualify as a stainless steel (10.5 to 11.75%) and is stabilized with titanium.

Type 429. A need for a higher degree of weldability than that provided by type 430 resulted in the development of type 429. Both alloys have the same carbon content; type 429, however, has a lower chromium content (14.0 to 16.0%). This carbon-chromium ratio allows type 429 to retain its ferritic status.

Types 430, 430F, 430FSe, 434, and 436. These three basic grades, plus the two modifications, represent the old and well-known 17-chrome stainless steel grade, which is the original type 430. Type 430 shows a high resistance against attack by practically all types of atmospheres and also by many types of chemicals, notably oxidizing acids. At times, type 430 replaces the more expensive 18-8 austenitic types.

Type 430F is a machinable grade of type 430. The additives contained in it do reduce the corrosion resistance of the basic type 430.

Type 434 has the same chromium content as type 430, but it also has a nominal 1.0% molybdenum content, which adds greatly to its resistance to certain types of corrosion, notably pitting corrosion.

Type 436 is essentially type 434, but it contains up to 0.70% niobium plus tantalum for carbide stabilization. It is, therefore, suited for elevated temperature applications as well as for room-temperature corrosion resistance.

Types 442 and 446. Frequently, types 442 and 446 are called "chrome-irons." They differ in composition only in chromium content 18.0 to 23.0% for type 442 and 23.0 to 27.0% for type 446. Neither is used to any great extent for corrosion resistance at room temperatures.

Their principal uses are in heat processing equipment where resistance to scaling is important, but strength and hardness are less so. Types 442 and 446 are capable of sustained operation at temperatures up to 980 °C (1800 °C) and 1095 °C (2000 °F), respectively, without experiencing destructive scaling.

Precipitation-Hardening Stainless Steels

There are six AISI types that make up the precipitation-hardening group of stainless steels. These are 630, 631, 632, 633, 634, and 660. There may be other compositions, but they are proprietary.

Accurate evaluation of the corrosion resistance of these types is difficult to summarize, partly because they differ widely in composition and in the formed microstructures. Most of the precipitation-hardening grades form semiaustenitic (duplex) structures. Some types, notably type 630, form a martensitic structure.

Corrosion Resistance. It is generally considered that the average corrosion resistance of the precipitation-hardening group approaches that of the 18-8 austenitic grades and that it is usually superior to the corrosion resistance of the martensitic and ferritic types.

Type 630. Copper is the principal hardening agent in type 630. Its corrosion resistance approaches that of types 302 and 304.

Type 631. In the heat treated condition, type 631 has a duplex structure. It has good corrosion resistance along with high strength.

Type 632. With the exception of an addition of molybdenum, type 632 is very much like type 630. There is an improvement in strength and resistance to pitting corrosion.

Type 633 is also a duplex-structure grade, but has a slightly higher alloy content than types 631 and 632. Thus, its corrosion resistance is better.

Type 634 is semiaustenitic (duplex), but it has an alloy content slightly less than type 633. It does, however, contain molybdenum, which promotes general corrosion resistance, specifically pitting corrosion.

Duplex Stainless Steels

The general corrosion resistance of the commercial duplex stainless steels varies according to the chromium, molybdenum, and nitrogen content. In most corrosive mediums the duplex steels are superior to types 304 and 316 steels. Type 7-Mo duplex steel shows a highly favorable rate of corrosion in boiling 65% nitric acid as contrasted with other stainless steels.

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Therefore, 7-Mo is used in nitric acid cooling condensers. It is also resistant in reducing mineral-acid mixtures containing nitric acid. It is superior to type 306 in phosphoric acid environments, in stronger organic acids, and in sulfuric acid.

Pitting Corrosion. The resistance of duplex stainless steels to pitting corrosion is also superior to that of type 304 or 316 stainless steels. The higher alloyed duplex stainless steels containing 25% chromium and 3% molybdenum have good corrosion resistance in seawater and even in hot seawater.

Under certain conditions, duplex stainless steels are used in CO_2 piping systems, as well as in certain sour gas down hole tubing in the petroleum industry.

Intergranular Corrosion. The resistance of the duplex steels to intergranular corrosion varies among the commercial alloys primarily as a function of the carbon content and the alpha-gamma phase balance. Alloys with high carbon content and a phase balance in favor of ferrite are susceptible to intergranular corrosion and require annealing after welding.

The large majority of commercial alloys have low carbon contents (>0.03%) and a 50 to 50 gamma-to-alpha ratio. They also have good resistance to intergranular corrosion. It has been reported that AF22 duplex steel (0.03% C, 21 to 23% Cr, 4.5 to 6.5% Ni, 2.5 to 3.5% Mo, 0.08 to 0.2% N) sensitized up to 30 h at 300 to 1000 °C (570 to 1830 °F) indicated no intergranular attack in the Strauss test. In the Huey test (ASTM A262, Practice C), a certain amount of corrosion loss was noticed and ascribed to gamma-phase and chi-phase formation.

The same research noted no intergranular attack in the Strauss or in the Huey test for welded material 5 mm (0.2 in.) thick.

Other research centering on the fabrication of pressure vessels made out of 44LN (0.03% C, 25% Cr, 6% Ni, 1.5% Mo, 0.17% N) duplex steel reported acceptable intergranular corrosion as tested by ASTM A262-79, Practice A and C.

Intergranular corrosion performance of the duplex steels must consider the alloy composition, the welding process, and the environment in which the fabricated equipment is to operate.

Stress-Corrosion Cracking. While duplex steels are susceptible to chloride-induced stress-corrosion cracking, they are clearly superior to the austenitic grades. The behavior is influenced by composition and phase balance; the higher the amount of ferrite, the better the resistance to stress corrosion. The threshold stress for stress corrosion of the duplex steels is superior to that of type 304. Similar to intergranular corrosion behavior, the resistance to stress-corrosion cracking of the duplex steels should take into consideration the composition, the phase balance, the stress level, and the environment.

Cast Steels

Steel casting compositions are, depending on the alloy content and intended service, generally divided into carbon, low-alloy, corrosion-resistant, or heat-resistant categories. Castings are classified as corrosion resistant if they are capable of sustained operation when exposed to attack by corrosive agents at service temperatures below 315 °C (600 °F).

Table 4 Petroleum corrosion resistance of cast steels

1000-h test in petroleum vapor under 780 N (175 lb) of pressure at 345 °C (650 °F)

Type of material	Weight loss, mg/cm²
Cast carbon steel	3040
Cast steel, 2Ni–0.75Cr	2370
Seamless tubing, 5% Cr	1540
Cast steel, 5Cr–1W	950
Cast steel, 3Cr–0.5Mo	730
Cast steel, 12% Cr	6.4
Stainless steel, 18Cr–8Ni	2.1

The term "corrosion resistance" is highly subjective in that its meaning depends entirely on the specific environment into which a metal or alloy is subjected. Carbon and most low-alloy steels are considered resistant only to the most mildly corrosive conditions. With the addition of one or more of the various alloying elements—principally chromium, nickel, molybdenum, or copper—general corrosion resistance tends to increase. The rate of increase depends largely on the nature of the environment. Also, even within the most constant of environmental conditions, the rate of increase in corrosion resistance is not, by any means, a straight line. This is clearly illustrated in Table 4:

Under specific environmental conditions, as noted above, the rate of corrosion, as measured by weight loss, is extremely high (3040 mg/cm^2) for plain-carbon steel. With the addition of 2.0% nickel and 0.75% chromium, the corrosion rate decreases substantially. With increasing amounts of alloying additions, the rate continues to decrease. When the chromium content is increased to 12.0%, a drastic decrease in the corrosion rate occurs. This is because, at this point, the cast chromium alloy qualifies as a stainless steel. For the higher alloy 18-8 stainless, the corrosion rate shows a further decrease. It becomes obvious that a number of variables directly influence corrosion rate. As the result, it is misleading for a reader to merely consult a list

comparative rates of different alloys exposed to the same corroding medium.

Any graphic or tabular data must be considered as guidelines, not as the basis of application selections. Alloy casting users are urged to consult with corrosion and materials specialists when a particular selection is to be made. Data derived from controlled laboratory tests should be cautiously applied to anticipated service conditions. The best source of information is obtained from equipment used under similar operating conditions. Still, exposing samples to actual service conditions also provides valuable data.

Carbon and Low-Alloy Cast Steels

Unless shielded by a protective coating, iron and steel corrodes in the presence of water and oxygen. The rate at which the process proceeds in the atmosphere depends on the corroding medium, the conditions of the particular location in which the material is used, and the steps taken to retard corrosion.

Cast steel and wrought steel of similar composition and heat treating conditions ordinarily exhibit about the same degree of corrosion resistance within the same environments. Plain-carbon steels and some of the low-alloy steels do not ordinarily resist drastic corrosive conditions, such as sulfuric acid (H_2SO_4). To significantly increase corrosion resistance, it is necessary to use extensive alloying additions.

Atmospheric Corrosion

In the most general terms, it can be stated that the corrosion rate of cast steel varies widely, depending on its specific location. For example, an unprotected plain-carbon steel placed outdoors corrodes slowly in the upper Midwest, whereas the same material rusts several times faster in an ocean harbor location where both temperature and humidity are high and where the air is contaminated with industrial fumes and saline fog.

As a rule, plain-carbon cast steels exposed to any kind of atmosphere should be coated—if only with paint—to realize an acceptable service life. However, there are notable cases where the life of a carbon steel with a very small alloy addition, such as 0.6% copper, can be substantially increased within a given atmosphere.

Exposure to Waters

The aggressiveness of waters as related to the service life of a cast steel also varies over a wide range. Carbon steels should not be considered for service in sea or brackish water without some sort of protection. Mine waters are also quite aggressive. However, the material often yields an acceptable service life when exposed to fresh or inhibited waters, as in boiler use. In such cases, the presence of oxygen is a major positive factor. If the steel is covered with water at all times, the rate of attack is minimized.

Soil Corrosion

Cast steel pipe has been tested for various periods up to 14 years in different types of soils. When compared with similar tests performed on wrought steel of like composition, the results of these tests indicated no significant difference in corrosion rate between the two materials. However, the actual rate of corrosion and rate of pitting of the cast pipe varied widely in direct relation to the specific soil and aeration conditions.

Iron-Base Superalloys

Iron-base superalloys are logically an extension of the stainless steel family, and a more complete description of corrosion behavior for these alloys may be gained by reading about those alloys. Most of the iron-base superalloys are high-chromium austenitic stainless steels to which enough titanium and sometimes aluminum have been added to generate a hardening precipitate such as gamma prime or eta phase. Under some circumstances, more significant alloy modifications have been made, particularly in the case of cast alloys.

Typical applications of iron-base superalloys have been as oxidation-resistant materials for steam and gas turbines, automotive applications, furnace structural components, and in the chemical-processing industry. The corrosion behavior of these materials is usually a direct function of their chromium content. Chromium contents frequently range between 20 and 30% for maximum protection, without creating the formation of the deleterious (to strength) sigma phase. Aluminum, when present, contributes to oxidation resistance. Carbon may combine with the chromium to produce carbides and so reduce the effective corrosion resistance of an alloy. Titanium and other stronger carbide formers may act to ensure maximum utilization of the available chromium by tying up carbon. Manganese, in amounts up to 5%, may provide some additional scale retention by reducing the volatility of the oxide at high temperatures. Active elements, including the rare earth elements, tend to promote oxide scale adherence.

The oxidation resistance of iron-base superalloys at temperatures below about 815 °C (1500 °F)—to which they should be restricted anyway for considerations of strength—depends largely upon chromium content. The level of oxidation resistance compares favorably with that of nickel- or cobalt-base superalloys. Use of iron-base alloys at higher temperatures generally results in an unfavorable comparison of them to nickel-base superalloys, because the latter are also usually

highly alloyed with aluminum, which produces, at elevated temperatures, aluminum oxide scale, a more protective film than chrome oxide. However, at lower temperatures in aqueous-corrosion conditions, iron-base superalloys offer good corrosion resistance at a more competitive cost than do nickel-base superalloys.

Selection for Corrosion Resistance

The selection of iron-base alloys for corrosion resistance is frequently limited by an obvious fact—it is generally clear that, as required oxidation resistance increases, so does the required chromium content. There is thus a natural tendency to choose nickel-base superalloys. However, considerations of fabricability, availability, and cost may be more important choice criteria than a prolonged selection program for the best alloy for oxidation resistance.

There are a great number of iron-base superalloys available, although this may not be obvious from the more common technical literature. Many of them are proprietary.

Aluminum and Aluminum Alloys

Aluminum and its alloys resist attack by a wide range of environments and many chemical compounds. Consequently, aluminum (along with stainless steel) is the metal most thought of by the public and engineering community when lower temperature corrosion resistance is considered. The widespread acceptance of aluminum in cookware, the beverage industry, and as home siding testifies to the utility and applicability of alloys of aluminum as a corrosion-resistant material. Table 5 gives comparative corrosion characteristics of aluminum alloys.

Corrosion Resistance

Resistance to corrosion is a relative consideration, because the environment significantly affects the nature of the attack. Aluminum and its alloys generally have excellent corrosion resistance in many different environments. When applying the material, conditions that cause corrosion of aluminum frequently are the exception rather than the rule.

Actually, aluminum, by virtue of its position in the electrom tive force series, is a highly reactive metal. Only magnesium, among the common structural metals, is more reactive Aluminum owes its excellent corrosion resistance to the barrier oxide film that forms on the metal and its alloys almost immediately in a wide variety of environments. Although the oxide film instantaneously formed on a freshly abraded surface of aluminum is thin (1 nm), it is extremely effective in preventing corrosion. On subsequent exposure to normal atmospheres, or when enhanced by artificial growth processes (anodizing), the film becomes much thicker. The oxide film offers reasonable protection to aluminum at elevated temperatures, but it is most effective in making aluminum passive at lower temperatures in atmospheric or aqueous corrosive conditions. The oxide film is virtually transparent, tough, adherent, and nonflaking. Consequently, once formed, it does not thicken or self-destruct with time under ordinary lower temperature exposure conditions. Because the oxide film is self-renewing, accidental abrasion of the surface film is rapidly repaired.

The conditions that promote corrosion of aluminum and its alloys, therefore, must be those that continuously abrade the film mechanically or promote chemical conditions that locally degrade the protective oxide film and minimize the availability of oxygen to rebuild it.

Maximum corrosion resistance is found with pure aluminum; however, its alloys are highly corrosion resistant to many environments as well. As with most materials, the presence of impurities on the surface or within the metal can significantly degrade corrosion resistance. Clean surfaces resist corrosion much more effectively than surfaces on which there are such deposits. Aluminum exposed to aggressive marine or industrial atmospheres last much longer if it is rained upon frequently or cleaned by water rinsing. Water dilutes and/or washes away the detrimental residues of salt, soot, etc., that accumulate with time. In certain organic chemicals, such as phenol, traces of water prevent corrosion that would otherwise occur.

An increase in temperature strongly influences the corrosion of aluminum in aqueous conditions. However, as the temperature increases in water, the rate of pitting attack is reduced. At the same time, in the atmosphere, moderate heat can be beneficial, because it increases the rate of drying, thereby reducing the period of wetness.

Corrodant velocity can also be an important factor in corrosion; increased movement of a corrosive liquid or gas in contact with the metal generally accelerates corrosion. As in many materials, extremely high velocities of liquids may promote cavitation.

The acidity or alkalinity of the immediate environment (chemical, soil, atmospheric, or aqueous) significantly affects the corrosion of aluminum. The Pourbaix diagram for aluminum with a hydrated aluminum oxide film shows immunity or passive behavior in the pH range of about 3 to 8.5. When aluminum is exposed to higher pH (alkaline) conditions, corrosion may occur, and when the oxide film is perforated locally, accelerated attack occurs, because aluminum is attacked more rapidly than its oxide under alkaline conditions. The result is pitting corrosion. In acidic conditions, the oxide is

Table 5 Comparative Corrosion Characteristics of Aluminum Alloys

Source: *Aluminum Standards and Data 1984,* The Aluminum Association, Washington, DC

Alloy and temper	Resistance to corrosion: General(a)	Resistance to corrosion: Stress-corrosion cracking(b)	Some applications of alloys
1060-0, H12, H14, H16, H18	A	A	Chemical equipment, railroad tank cars
1100-0, H12, H14, H16, H18	A	A	Sheet metal work, spun hollowware, fin stock
1350-0, H12, H14, H16, H18, H111, H24, H26	A	A	Electrical conductors
2011-T3, T4, T451	D(c)	D	Screw machine products
2011-T8	D	B	
2014-T3, T4, T451	D(c)	C	Truck frames, aircraft structures
2014-T6, T651, T6510, T6511	D	C	
2017-T4, T451	D(c)	C	Screw machine products, fittings
2024-T4, T3, T351, T3510, T3511, T361	D(c)	C	Truck wheels, screw machine products, aircraft structures
2024-T6, T81, T851, T8510, T8511, T861	D	B	
2025-T6	D	C	Forgings, aircraft propellers
2036-T4	C	...	Auto body panel sheet
2117-T4	C	A	Rivets
2218-T61, T72	D	C	Jet engine impellers and rings
2219-T31, T351, T3510, T3511, T37	D(c)	C	Structural uses at high temperatures (to 600 °F), high-strength weldments
2219-T81, T851, T8510, T8511, T87	D	B	
2618-T61	D	C	Aircraft engines
3003-0, H12, H14, H16, H18, H25	A	A	Cooking utensils, chemical equipment, pressure vessels, sheet metal work, builder's hardware, storage tanks
3004-0, H32, H34, H36, H38	A	A	Sheet metal work, storage tanks
3105-0, H12, H14, H16, H18, H25	A	A	Residential siding, mobile homes, rain carrying goods, sheet metal work
4032-T6	C	B	Pistons
5005-0, H12, H14, H16, H18, H32, H34, H36, H38	A	A	Appliances, utensils, architectural, electrical conductor
5050-0, H32, H34, H36, H38	A	A	Builder's hardware, refrigerator trim, coiled tubes
5052-0, H32, H34, H36, H38	A	A	Sheet metal work, hydraulic tube, appliances
5056-0, H111, H12, H14, H32, H34	A(d)	B(d)	Cable sheathing, rivets for magnesium, screen wire, zippers
5056-H18, H38	A(d)	C(d)	
5056-H192, H392	B(d)	D(d)	
5083-0, H111, H116, H321	A(d)	B(d)	Unfired welded pressure vessels, marine, auto aircraft cryogenics, TV towers, drilling rigs, transportation equipment, missile components
5086-0, H111, H116, H32	A(d)	A(d)	
5086-H34, H36, H38	A(d)	B(d)	
5154-0, H32, H34, H36, H38	A(d)	A(d)	Welded structures, storage tanks, pressure vessels, salt water service
5252-H24, H25, H28	A	A	Automotive and appliance trim
5254-0, H32, H34, H36, H38	A(d)	A(d)	Hydrogen peroxide and chemical storage vessels
5454-0, H111, H32, H34	A	A	Welded structures, pressure vessels, marine service
5456-0, H116, H321	A(d)	B(d)	High-strength welded structures, pressure vessels, marine applications, storage tanks
5457-0	A	A	Automotive parts, appliance trim
5652-0, H32, H34, H36, H38	A	A	Hydrogen peroxide and chemical storage vessels
5657-H241, H25, H26, H28	A	A	Anodized auto and appliance trim
6053-T6, T61	A	A	Wire and rod for rivets
6061-0, T6, T651, T652, T6510, T6511	B	A	Heavy-duty structures requiring good corrosion resistance, truck and marine, railroad cars, furniture, pipelines
6061-T4, T451, T4510, T4511	B	B	
6063-T1, T4, T5, T52, T6, T83, T831, T832	A	A	Pipe railing, furniture, architectural extrusions
6066-0	C	A	Forgings and extrusion for welded structures
6066-T4, T4510, T4511, T6, T6510, T6511	C	B	
6070-T4, T4511, T6	B	B	Heavy-duty welded structures, pipelines
6101-T6, T61, T63, T64	A	A	High-strength bus conductors
6201-T81	A	A	High-strength electric conductor wire
6262-T6, T651, T6510, T6511, T9	B	A	Screw machine products
6463-T1, T5, T6	A	A	Extruded architectural and trim sections
7001-0, T6, T6510, T6511	C(c)	C	High-strength structures
7049-T73, T7352	C	B	Aircraft forgings
7050-T73510, T73511, T74(e), T7451(e), T74510(e), T74511(e), T7452(e), T7651, T76510, T76511	C	B	Aircraft and other structures
7075-T6, T651, T6510, T6511, T652	C(c)	C	Aircraft and other structures
7075-T73, T7351	C	B	
7178-T6, T651, T6510, T6511	C(c)	C	Aircraft and other structures
8017-H12, H22, H221	A	A	Electrical conductors
8030-H12, H221	A	A	Electrical conductors
8176-H14, H24	A	A	Electrical conductors
8177-H13, H221, H23	A	A	Electrical conductors

(a) Ratings A through E are relative ratings in decreasing order of merit, based on exposures to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial and seacoast atmospheres without protection. Alloys with C, D, and E ratings generally should be protected, at least on faying surfaces.
(b) Stress-corrosion cracking ratings are based on service experience and on laboratory tests of specimens exposed to the 3.5% sodium chloride alternate immersion test. A, no known instance of failure in service or in laboratory tests; B, no known instance of failure in service, limited failures in laboratory tests of short transverse specimens; C, service failures with sustained tension stress acting in short transverse direction relative to grain structure, limited failures in laboratory tests of long transverse specimens; D, limited service failures with sustained longitudinal or long transverse stress.
(c) In relatively thick sections, the rating would be E.
(d) This rating may be different for material held at elevated temperature for long periods.
(e) T74-type tempers, although not previously registered, have appeared in various literature and specifications as T736-type tempers.

more rapidly attacked than aluminum, and more general attack should result.

Effects of Alloying Elements

Generally, the higher the degree of purity of the aluminum or its alloys, the greater the corrosion resistance. Certain elements such as magnesium or manganese, in amounts less than about 1%, can be alloyed with pure aluminum without seriously reducing the corrosion resistance of the pure metal in many environments. Up to 1% magnesium or up to about 1.25% manganese can be added to high-purity aluminum without increasing the pitting probability factor in water. Depending on the precise purity of pure aluminum, pitting may even be reduced.

The principal alloying elements (copper, magnesium, silicon, and zinc) added to aluminum reduce the atmospheric corrosion resistance somewhat. More significantly, they affect other localized corrosion resistance (stress-corrosion cracking and exfoliation corrosion, for example).

Magnesium

Magnesium in nonhardening type alloys (5000 series) makes them especially immune to aqueous corrosion. The magnesium-silicide alloys (6000 series) offer excellent aqueous corrosion resistance in a stronger material. The copper (2000 series) and zinc (7000 series) alloys are generally much less resistant to aqueous corrosion. Cladding techniques, as discussed below, afford protection for many applications.

Magnesium somewhat increases the resistance of aluminum to corrosion in alkaline solutions, but when present in the grain boundaries as an anodic magnesium aluminum compound, it may promote stress-corrosion cracking and intergranular corrosion. Silicon in small amounts (0.1%) has little effect on pitting corrosion of aluminum, yet greater amounts reduce resistance to pitting. Silicon has a detrimental influence on the resistance of aluminum to seawater.

Chromium

Chromium when added to aluminum-magnesium or aluminum-magnesium-zinc alloys, is used in very small amounts (0.1 to 0.3%) and has a beneficial effect on corrosion resistance. Chromium improves resistance to stress-corrosion cracking in high-strength alloys, but in super-purity aluminum it increases the pitting potential in water. Iron, although not an intentional alloy addition, is the main cause of pitting in aluminum alloys. Its effects may be mitigated by other alloying additions.

Copper

Copper reduces the corrosion resistance of aluminum more than any of the common alloying elements. It can lead to a higher rate of uniform corrosion, greater occurrence of pitting, intergranular corrosion, and stress-corrosion cracking. At low levels (about 0.15%) of copper, the pitting resistance of commercial aluminum is decreased, especially in seawater. In higher copper content alloys (2000 series), the effect of the element is related directly to the fabrication process and heat treatment. At higher copper contents, intergranular corrosion or stress-corrosion cracking are areas of concern.

Zinc

Zinc has only a small influence on the corrosion resistance of commercial aluminum. It may reduce the resistance to acidic media, but improve the resistance to alkaline solutions. When zinc is present in higher levels and in combination with magnesium and copper, the influence of zinc is a function of the fabrication and heat treatment of the alloy. The high-zinc alloys may be susceptible to intergranular corrosion, stress-corrosion cracking, and exfoliation corrosion.

Lithium

Lithium additions are now made to some aluminum alloys. Although lithium is a highly reactive element, the addition of up to 3% lithium makes aluminum only slightly more anodic. Little has been published on the corrosion resistance of lithium-containing alloys, however. In an electrochemical comparison of an aluminum-lithium-magnesium alloy to AA-7075 (aluminum-zinc-magnesium), the lithium alloy exhibited more active corrosion and pitting potentials, along with a higher current density for passivation.

Coatings and Surface Treatments

Although aluminum is highly resistant to corrosion, it is possible to enhance its corrosion resistance with coatings or surface treatment. One of the best ways to enhance the corrosion resistance of aluminum alloy plate is to apply a cladding of pure aluminum on one or both sides. This process produces materials known as "Alclad." Alclad is not restricted to the use of pure aluminum on an alloy; it is possible to bond a more corrosion-resistant alloy to a less corrosion-resistant substrate. Pipe also may be Alcladed, but other shapes or forms present fabrication problems. It is possible to clad an alloy by spraying, yet it is not customarily a cost-effective process.

One of the most important characteristics of aluminum is the ease with which the normally protective oxide film can be enhanced. The surface of aluminum can be altered by chemical and electrochemical treatments to thicken the normal oxide film. Proprietary chemical conversion treatments can produce films that may be the basis for subsequent painting (the films greatly improve paint adhesion to aluminum) and are the basis for the coatings applied to house sidings. Such films are not as effective (when unpainted) as anodized films in providing enhanced corrosion protection.

Copper and Copper Alloys

Copper and copper alloys have been widely used for centuries in many applications because of their excellent corrosion resistance and moderate cost. Despite the formation of the common green patina in natural environments, copper and its alloys corrode at negligible rates in unpolluted water or air and in deaerated nonoxidizing acids. For marine applications, it is known that copper shows resistance to biofouling. Copper alloys resist many saline solutions, neutral or slightly alkaline solutions, and organic chemicals. In strongly reducing conditions at temperatures from about 290 to 400 °C (550 to

750 °F), copper alloys are often superior to stainless steels and other stainless alloys.

Copper and its alloys, however, may be susceptible to more rapid attack in oxidizing acids, oxidizing heavy metal salts, as well as sulfur, ammonia, and some of their compounds. Resistance to acid solutions depends on the alloy composition, specific acid, and the severity of oxidizing conditions in the solutions.

In general, copper and its alloys are used at ambient temperatures when exposed to gaseous environments, but some types are used in gaseous environments at moderately elevated temperatures where they operate in oxidizing conditions. Copper alloys are exposed to liquid/gas environments at fairly high temperatures when used as heat exchangers. The nature of the environment, including treatment of the cooling water, velocity of the cooling water, and various other factors all determine the actual susceptibility of copper alloys to corrosion under these conditions. Copper and brasses are susceptible to erosion-corrosion or impingement attack.

Corrosion-resistant applications of copper and its alloys are extensive; they are used in fresh water supply lines and plumbing fixtures and also in seawater supply lines, heat exchangers, and condensers, paper-making belts, as well as architectural elements and decoration. Table 6 gives corrosion ratings of wrought copper alloys in various corrosive media.

Though classed as corrosion resistant, neither copper nor its alloys form the truly passive corrosion-resistant film that characterizes most true corrosion-resistant alloys. In aqueous environments at ambient temperatures, cuprous oxide forms the protective scale. Alloy additions of aluminum, tin, zinc, and nickel are used to dope the corrosion product films to enhance the natural corrosion resistance of copper and to produce the range of corrosion-resistant capability for which copper alloys are noted.

Copper alloys can be quite susceptible to stress-corrosion cracking. The classic example of stress-corrosion cracking is the "season cracking" of cartridge brass (70 copper-30 zinc). While zinc is the principal culprit, small amounts of phosphorus, arsenic, antimony, silicon, aluminum, or nickel have been found to produce stress-corrosion cracking of copper in ammoniacal solutions. As for other elements, corrosion-resistant behavior of copper is best revealed by considering its alloy systems. The basic systems for copper are copper-tin (bronze), copper-zinc (brass), copper-nickel (cupronickels), and variations of the above, including aluminum-bronzes, phosphor-bronzes, and nickel-silvers. A discussion of the role in corrosion resistance of the principal alloy additions that produce these systems follows.

Zinc

Zinc content in copper can range from a few percent to about 40%. The resistance of brasses to corrosion does not change markedly as long as the zinc content is 15%, or less. When the zinc content exceeds 15%, the alloy may be susceptible to dezincification. This is a process involving the leaching of the zinc from the alloy. It results in a porous, reduced ductility, reddish copper matrix. What remains may support a given load until an increase of pressure or weight exceeds the local ductility and causes fracture. Soft, stagnant, or slow moving waters or saline solutions can lead to dezincification of unmodified brasses. The brasses may be more prone to dezincification in stressed regions (for example, in the bent region of a float arm on a water closet fixture) or where a bend exists (as in an elbow in a fresh water supply line).

High zinc content introduces the possibility of stress-corrosion cracking. Very high zinc content, as in Muntz metal, may lead to excessive corrosion attack in seawater due to dezincification. Limited or no data are available on the effects of zinc in brasses on the rate of corrosion; however, the addition of tertiary and quaternary elements is known to enhance the resistance of zinc-containing alloys to certain environments.

Tin

Tin bronzes are essentially solid solutions of tin in copper. Phosphorus is commonly used as a deoxidizer, and the residual phosphorus content gives rise to the term "phosphor bronze." The addition of tin to copper promotes good resistance to fresh and seawaters. Under some conditions, when more than 5% tin is present, the corrosion resistance in marine applications is enhanced. Where the water velocity is high, tin content for marine applications of copper alloys should exceed 5%. Alloys containing between 8 and 10% tin have high resistance to impingement attack.

Tin bronzes tend to have intermediate pitting resistance. When tin is added to some brasses, the corrosion resistance is substantially increased; in fact, 1% tin inhibits dealloying (dezincification) in 70 copper-30 zinc alloys.

Nickel

Nickel and copper are mutually soluble, and in alloys where copper is the dominant element, commercial alloys range from about 54 to over 90% copper. Nickel provides the best general resistance to aqueous corrosion of all the commercially important alloy elements. It promotes resistance to impingement corrosion and to stress-corrosion cracking.

The addition of nickel to copper-zinc alloys produces nickel-silver alloys. Most commonly these have about 18% nickel and 55 to 65% copper. Such alloy additions promote good resistance to corrosion in both fresh and salt waters. The nickel inhibits dezincification. Nickel-silvers are much more corrosion resistant in saline solutions than brasses of similar copper content.

Other elements

Other elements are added to copper alloys in varying amounts to introduce favorable corrosion characteristics. For example, 2% aluminum is added to 76 copper-22 zinc solutions to produce aluminum brass, and a small amount of arsenic (less than 0.10%) is added to the alloy to inhibit dezincification.

Table 6 Corrosion Resistance of Copper and Copper Alloys to Various Environments

A, suitable under most conditions of use; B, good corrosion resistance, may be considered in place of a metal with an A rating when some property other than corrosion resistance governs its use; C, fair corrosion resistance; D, not suitable
Source: Arco Metals Company—American Brass, Rolling Meadows, IL

Environment	Copper: Electrolytic tough pitch 110	Copper: Phosphorized 122	Low-zinc brass: Commercial bronze 220	Low-zinc brass: Red brass 230	High-zinc brass: Cartridge brass 260	High-zinc brass: Architectural bronze 385	High-zinc brass: Muntz metal 280	Special brass: Tobin bronze 4641	Special brass: Arsenical admiralty 443	Special brass: Ambraloy 687	Phosphor bronze: Phosphor bronze (A) 510	Phosphor bronze: Phosphor bronze (D) 524	Aluminum bronze: Ambraloy 630	Copper-silicon alloys: Everdur 655	Copper-silicon alloys: Everdur 651	Cupronickel: Cupronickel, 10% 706	Cupronickel: Cupronickel, 30% 715	Nickel silver: Nickel silver, 18% 752
Acetic acid	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Acetic anhydride	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Acetone	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acetylene(a)	D	D	D	D	D	A	A	A	D	D	D	D	D	D	D	D	D	D
Alcohols	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Alum	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	A	B
Alumina	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Aluminum chloride	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Aluminum hydroxide	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Aluminum sulfate	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	A	B
Ammonia, absolutely dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ammonia, moist	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	D
Ammonium hydroxide	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	D
Ammonium chloride	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	D
Ammonium nitrate	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C	D
Ammonium sulfate	C	C	C	C	D	D	D	D	D	D	C	C	C	C	C	C	B	C
Amyl acetate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Amyl alcohol	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Aniline	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Aniline dyes	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Asphalt	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Atmosphere, industrial	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Atmosphere, marine	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Atmosphere, rural	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Barium carbonate	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Barium chloride	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Barium hydroxide	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Barium sulfate	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Barium sulfide	C	C	C	C	B	B	B	B	B	B	C	C	C	C	C	C	B	B
Beer(b)	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Beet sugar syrups	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Benzine	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Benzoic acid	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Benzol	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Black liquor, sulfate process	C	C	C	C	D	D	D	D	D	C	C	C	C	C	C	C	B	C
Bleaching powder, wet	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Borax	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Bordeaux mixture	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Boric acid	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Brines	B	B	B	B	D	D	D	C	B	B	B	A	B	B	B	A	A	A
Bromine, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Bromine, moist	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Butane	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Butyl alcohol	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Butyric acid	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Calcium bisulfite	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Calcium chloride	B	B	B	B	D	D	D	C	B	B	B	A	B	B	B	A	A	A
Calcium hydroxide	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Calcium hypochlorite	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Cane sugar syrups	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Carbolic acid	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Carbon dioxide, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

(a) Copper and copper alloys are not attacked by dry gases at room temperature or lower. Acetylene forms an explosive compound with copper when moist and alloys containing more than 65% Cu should not be used with the wet gas under pressure. Moist carbon dioxide is corrosive to brasses high in zinc, but may be handled by other copper alloys. Tin coatings are highly resistant to moist carbon dioxide. Moist chlorine gas is corrosive to all copper alloys. Sulfur dioxide and sulfur trioxide in the presence of moisture form sulfurous and sulfuric acid, respectively. Copper, red brass, Everdur, phosphor bronze and cupronickel, 30% 715 should be considered for handling these gases when moist.

(b) Copper and its alloys are resistant to corrosion by most foods and beverages. However, consideration must be given to the possibility that such products handled in equipment made of copper or its alloys may dissolve traces of copper in amounts sufficient to discolor the product or alter its taste. In such cases it is recommended that the metal be tin-coated.

(c) Copper alloys are resistant to most organic solvents such as the acetates, alcohols, aldehydes, ketones, petroleum solvents, and ether. Organic acids in aqueous solution may be handled by copper and most copper alloys, but corrosion will be accelerated if air is present. Binary copper-zinc alloys containing more than 15% Zn may be attacked by dezincification corrosion. Copper alloys may be definitely corroded by chloride hydrocarbons, such as carbon tetrachloride and trichloroethylene, at the boiling point in the presence of moisture unless the hydrocarbons are stabilized by a neutralizer. Of the copper alloys, cupronickel, 30% 715 and tin-coated metal offer the best resistance to moist chloride hydrocarbons.

(d) Copper and copper alloys are rapidly corroded by oxidizing acids such as nitric and chromic. Corrosion by other acids is generally dependent on the presence of oxygen or some other oxidizing agent in the solution. Brasses containing not more than 15% Zn, and special brasses, can be used with many acids, but, in general, high-zinc brasses should not be used with acids due to the danger of rapid corrosion by dezincification. Copper, red brass, phosphor bronze, Everdur, aluminum bronze, and cupronickel offer good resistance to corrosion by hot and cold dilute sulfuric acid and to corrosion by cold concentrated sulfuric acid. Intermediate concentrations of sulfuric acid sometimes are less corrosive to copper alloys than either concentrated acid or dilute acid. Concentrated sulfuric acid may be corrosive at elevated temperatures due to breakdown of the acid with the formation of metallic sulfides and sulfur dioxide gas causing localized pitting attack. Tests indicate that the copper alloys may be corroded by pitting attack by 90 to 95% sulfuric acid at about 50 °C (122 °F), by 80% acid at about 71 °C (160 °F), and by 60% acid at about 100 °C (212 °F).

(Continued)

Table 6 (continued)

Environment	Copper: Electrolytic tough pitch 110	Copper: Phosphorized 122	Low-zinc brass: Commercial bronze 220	Low-zinc brass: Red brass 230	High-zinc brass: Cartridge brass 260	High-zinc brass: Architectural bronze 385	High-zinc brass: Muntz metal 280	Special brass: Tobin bronze 4641	Special brass: Arsenical admiralty 443	Special brass: Ambraloy 687	Phosphor bronze: Phosphor bronze (A) 510	Phosphor bronze: Phosphor bronze (D) 524	Aluminum bronze: Ambraloy 630	Copper-silicon alloys: Everdur 655	Copper-silicon alloys: Everdur 651	Cupronickel: Cupronickel, 10% 706	Cupronickel: Cupronickel, 30% 715	Nickel silver: Nickel silver, 18% 752
Carbon dioxide, moist	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Carbonated water	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Carbonated beverages(b)	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Carbon disulfide	B	B	B	B	A	A	A	A	A	A	B	B	B	B	B	B	B	B
Carbon tetrachloride, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Carbon tetrachloride, moist(c)	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	A	B
Castor oil	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Chlorine, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Chlorine, moist	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	B	C
Chloracetic acid	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Chloroform, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Chromic acid	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Cider(b)	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Citric acid(b)	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Coffee(b)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Copper chloride	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Copper nitrate	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Copper sulfate	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Corn oil(b)	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Cottonseed oil(b)	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Creosote	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Crude oil	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	A	B
Ethers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethyl acetate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Ethyl alcohol	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethyl chloride	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Ethylene glycol	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Ferric chloride	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Ferric sulfate	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Ferrous chloride	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Ferrous sulfate	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Formaldehyde	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Formic acid	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Freon	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Fruit juices(b)	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Fuel oil	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Furfural	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Gasoline	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Gelatine(b)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glucose(b)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glue	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Glycerine	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrobromic acid	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Hydrocarbons, pure	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrochloric acid	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Hydrocyanic acid	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Hydrofluoric acid	C	C	C	C	D	D	D	D	D	D	C	C	C	C	C	C	B	C
Hydrofluosilicic acid	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Hydrogen	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrogen peroxide	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Hydrogen sulfide, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrogen sulfide, moist	D	D	D	D	C	C	C	C	C	C	D	D	C	D	D	D	C	C
Kerosene	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lacquers	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lacquer solvents	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lactic acid(b)	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A

(a) Copper and copper alloys are not attacked by dry gases at room temperature or lower. Acetylene forms an explosive compound with copper when moist and alloys containing more than 65% Cu should not be used with the wet gas under pressure. Moist carbon dioxide is corrosive to brasses high in zinc, but may be handled by other copper alloys. Tin coatings are highly resistant to moist carbon dioxide. Moist chlorine gas is corrosive to all copper alloys. Sulfur dioxide and sulfur trioxide in the presence of moisture form sulfurous and sulfuric acid, respectively. Copper, red brass, Everdur, phosphor bronze and cupronickel, 30% 715 should be considered for handling these gases when moist.
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(d) Copper and copper alloys are rapidly corroded by oxidizing acids such as nitric and chromic. Corrosion by other acids is generally dependent on the presence of oxygen or some other oxidizing agent in the solution. Brasses containing not more than 15% Zn, and special brasses, can be used with many acids, but, in general, high-zinc brasses should not be used with acids due to the danger of rapid corrosion by dezincification. Copper, red brass, phosphor bronze, Everdur, aluminum bronze, and cupronickel offer good resistance to corrosion by hot and cold dilute sulfuric acid and to corrosion by cold concentrated sulfuric acid. Intermediate concentrations of sulfuric acid sometimes are less corrosive to copper alloys than either concentrated acid or dilute acid. Concentrated sulfuric acid may be corrosive at elevated temperatures due to breakdown of the acid with the formation of metallic sulfides and sulfur dioxide gas causing localized pitting attack. Tests indicate that the copper alloys may be corroded by pitting attack by 90 to 95% sulfuric acid at about 50 °C (122 °F), by 80% acid at about 71 °C (160 °F), and by 60% acid at about 100 °C (212 °F).

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Lime	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lime-sulfur	C	C	C	C	B	B	B	B	B	B	C	C	C	C	C	C	B	B
Linseed oil	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Magnesium chloride	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Magnesium hydroxide	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Magnesium sulfate	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Mercury	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Mercury salts	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Methyl alcohol	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Methyl chloride, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Milk(b)	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Mine water	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Natural gas	B	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Nitric acid	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Nitrogen	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Oleic acid	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Oxalic acid	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Oxygen	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Palmitic acid	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Paraffin	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Phosphoric acid	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Potassium carbonate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Potassium chloride	B	B	B	B	D	D	D	C	B	B	B	A	B	B	B	A	A	A
Potassium chromate	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Potassium cyanide	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Potassium dichromate, acid	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Potassium hydroxide	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	A	A	A
Potassium sulfate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Propane	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Rosin	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Seawater	B	B	B	B	C	C	C	B	A	A	B	A	A	B	B	A	A	A
Sewage	A	A	A	A	C	C	C	B	A	A	A	A	A	A	A	A	A	A
Silver salts	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Soap solutions	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sodium bicarbonate	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	A	A	A
Sodium bisulfate	B	B	B	B	D	D	D	C	B	B	B	B	B	B	B	A	A	A
Sodium bisulfite	B	B	B	B	D	D	D	C	B	B	B	B	B	B	B	A	A	A
Sodium carbonate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sodium chloride	B	B	B	B	D	D	D	C	B	B	B	A	B	B	B	A	A	A
Sodium chromate	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sodium cyanide	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Sodium dichromate, acid	D	D	D	D	D	D	D	D	D	D	D	D	D	B	D	D	D	D
Sodium hydroxide	B	B	B	B	C	C	C	C	B	B	B	B	B	D	B	A	A	A
Sodium hypochlorite	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	B	B
Sodium nitrate	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	A	A	A
Sodium peroxide	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	B	B	B
Sodium phosphate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sodium silicate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sodium sulfate	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sodium sulfide	A	C	C	C	B	B	B	B	B	B	C	C	C	C	C	C	B	B
Sodium sulfite	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B
Sodium thiosulfate	C	C	C	C	B	B	B	B	B	B	C	C	C	C	C	C	B	B
Steam	A	A	A	A	C	C	C	A	A	A	A	A	A	B	B	A	A	A
Stearic acid	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	B	B
Sugar solutions	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Sulfur, dry	B	B	B	B	A	A	A	A	A	B	B	B	B	B	B	B	A	B

(a) Copper and copper alloys are not attacked by dry gases at room temperature or lower. Acetylene forms an explosive compound with copper when moist and alloys containing more than 65% Cu should not be used with the wet gas under pressure. Moist carbon dioxide is corrosive to brasses high in zinc, but may be handled by other copper alloys. Tin coatings are highly resistant to moist carbon dioxide. Moist chlorine gas is corrosive to all copper alloys. Sulfur dioxide and sulfur trioxide in the presence of moisture form sulfurous and sulfuric acid, respectively. Copper, red brass, Everdur, phosphor bronze and cupronickel, 30% 715 should be considered for handling these gases when moist.
(b) Copper and its alloys are resistant to corrosion by most foods and beverages. However, consideration must be given to the possibility that such products handled in equipment made of copper or its alloys may dissolve traces of copper in amounts sufficient to discolor the product or alter its taste. In such cases it is recommended that the metal be tin-coated.
(c) Copper alloys are resistant to most organic solvents such as the acetates, alcohols, aldehydes, ketones, petroleum solvents, and ether. Organic acids in aqueous solution may be handled by copper and most copper alloys, but corrosion will be accelerated if air is present. Binary copper-zinc alloys containing more than 15% Zn may be attacked by dezincification corrosion. Copper alloys may be definitely corroded by chloride hydrocarbons, such as carbon tetrachloride and trichloroethylene, at the boiling point in the presence of moisture unless the hydrocarbons are stabilized by a neutralizer. Of the copper alloys, cupronickel, 30% 715 and tin-coated metal offer the best resistance to moist chloride hydrocarbons.
(d) Copper and copper alloys are rapidly corroded by oxidizing acids such as nitric and chromic. Corrosion by other acids is generally dependent on the presence of oxygen or some other oxidizing agent in the solution. Brasses containing not more than 15% Zn, and special brasses, can be used with many acids, but, in general, high-zinc brasses should not be used with acids due to the danger of rapid corrosion by dezincification. Copper, red brass, phosphor bronze, Everdur, aluminum bronze, and cupronickel offer good resistance to corrosion by hot and cold dilute sulfuric acid and to corrosion by cold concentrated sulfuric acid. Intermediate concentrations of sulfuric acid sometimes are less corrosive to copper alloys than either concentrated acid or dilute acid. Concentrated sulfuric acid may be corrosive at elevated temperatures due to breakdown of the acid with the formation of metallic sulfides and sulfur dioxide gas causing localized pitting attack. Tests indicate that the copper alloys may be corroded by pitting attack by 90 to 95% sulfuric acid at about 50 °C (122 °F), by 80% acid at about 71 °C (160 °F), and by 60% acid at about 100 °C (212 °F).

(Continued)

Table 6 (continued)

	Copper		Low-zinc brass		High-zinc brass			Special brass			Phosphor bronze		Aluminum bronze	Copper-silicon alloys		Cupro-nickel		Nickel silver
Environment	Electrolytic tough pitch 110	Phosphorized 122	Commercial bronze 220	Red brass 230	Cartridge brass 260	Architectural bronze 385	Muntz metal 280	Tobin bronze 4641	Arsenical admiralty 443	Ambraloy 687	Phosphor bronze (A) 510	Phosphor bronze (D) 524	Ambraloy 630	Everdur 655	Everdur 651	Cupronickel, 10% 706	Cupronickel, 30% 715	Nickel silver, 18% 752
Sulfur, molten	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Sulfur chloride, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfur dioxide, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfur dioxide, moist	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	C	C	C
Sulfur trioxide, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sulfuric acid(d)	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Sulfurous acid	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	C	C	C
Tannic acid	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Tar	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Tartaric acid(b)	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Toluene	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Trichloracetic acid	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Trichloroethylene, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Trichloroethylene, moist	B	B	B	B	C	C	C	C	B	B	B	B	B	B	B	B	A	B
Turpentine	A	A	A	A	B	B	B	B	A	A	A	A	A	A	A	A	A	A
Varnish	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Vinegar(b)	B	B	B	B	D	D	D	D	C	C	B	B	B	B	B	B	B	B
Water, potable	A	A	A	A	C	C	C	C	A	A	A	A	A	A	A	A	A	A
Zinc chloride	C	C	C	C	D	D	D	D	C	C	C	C	C	C	C	C	C	C
Zinc sulfate	B	B	B	B	D	D	D	D	B	B	B	B	B	B	B	B	B	B

(a) Copper and copper alloys are not attacked by dry gases at room temperature or lower. Acetylene forms an explosive compound with copper when moist and alloys containing more than 65% Cu should not be used with the wet gas under pressure. Moist carbon dioxide is corrosive to brasses high in zinc, but may be handled by other copper alloys. Tin coatings are highly resistant to moist carbon dioxide. Moist chlorine gas is corrosive to all copper alloys. Sulfur dioxide and sulfur trioxide in the presence of moisture form sulfurous and sulfuric acid, respectively. Copper, red brass, Everdur, phosphor bronze and cupronickel, 30% 715 should be considered for handling these gases when moist.
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Significant amounts of aluminum (5 to 12%) are added to the copper-nickel-iron-silicon-tin system to produce the aluminum bronzes. Aluminum bronzes provide a substantial range of corrosion resistance. Environments that should be avoided include nitric acid, some metallic salts (ferric chloride), moist chlorinated hydrocarbons, and moist ammonia. Exposure to the latter medium could trigger stress corrosion.

Coatings

Metallic coatings are not used for corrosion protection as on some materials. One of the distinctive features of copper is its color, especially that of the high-copper alloys. These are prone to tarnish with exposure in the natural environment. Organic coatings (lacquers) were developed to protect the finish of architectural copper. These types of coatings have limited applicability, especially when wear becomes a problem. The more corrosion-resistant copper alloys such as the cupronickels and nickel-silver are very tarnish resistant and do not seem to require a coating for protection.

Selection for Corrosion Resistance

Experience has been the best criterion for selecting the most suitable alloy for a given environment. To take advantage of experience, the corrosion curves in this book should be reviewed, manufacturers should be contacted for additional literature, and corrosion ratings compiled by trade/industry associations such as the Copper Development Association should be requested. There is no guaranteed way to determine the acceptability of a material in a given environment without some sort of laboratory or pilot plant trial. Short-term tests may be made to verify the approximate relationships shown by the corrosion data for copper and its alloys in this book. Long-term tests may show a different behavior. It is important to keep in mind that general corrosion data relates to general attack; if you have localized attack, such as pitting or crevice corrosion, published data may be irrelevant. It generally is understood that copper and its alloys provide a high level of corrosion resistance in a variety of media at reasonable costs. When selecting a material for an application, keep in mind that copper or its alloys may offer a lower cost corrosion alternative to stainless steels and nickel-base alloys.

Magnesium and Magnesium Alloys

Magnesium is rarely used for structural purposes in the unalloyed condition. Consequently, only the corrosion resistance of magnesium-base alloys is of principal concern. Magnesium is an active element and ranges at or near the top of the galvanic series when magnesium-base alloys are being considered. Despite its high ranking in electrochemical reactivity, magnesium is successfully used in a wide variety of industrial applications, including tool parts, ladders, gear boxes, etc. Table 7 gives the suitability of testing magnesium in various substances.

Magnesium alloys are resistant to atmospheric corrosion because protective films form in a process similar to the formation of film in the active metal aluminum. When corrosion does occur, it is the result of the breakdown of this protective film.

Magnesium corrosion can be accelerated by galvanic coupling, high levels of certain impurities (especially nickel, copper, and iron), or contamination (especially of castings) by salts. The principal rate-limiting factors in the atmospheric (aqueous) corrosion of magnesium alloys are associated with the breakdown of the magnesium hydroxide film and the rate of its reformation. Magnesium alloys are anodic to all other structural metals and will undergo galvanic attack if coupled to them. The attack is especially severe if the other metal in the couple is passive or inert as, for example, stainless steels or copper-base alloys.

Magnesium is prone to the usual forms of corrosion, but is especially susceptible to pitting. This effect is the logical consequence of the natural breakdown of the protective film in selective locations. It can also be caused by the selective location of impurities either within the alloy or on its surface. Some magnesium alloys are susceptible to stress-corrosion cracking, but this occurs mainly in alloys containing over about 1.5% aluminum. The tendency toward stress-corrosion cracking increases with increasing aluminum content. Under some circumstances, magnesium alloys are attacked by filiform corrosion or crevice corrosion.

At relative humidities below about 90%, magnesium alloys do not show extensive general corrosion by interior atmospheres. However, as humidity approaches 100%, more extensive tarnish films may form. While the thicknesses of such films are only of minor importance from an appearance point of view, they may be very significant to performance of a component such as a computer disk drive made of die cast magnesium alloy. Coatings or surface treatment can reduce the risk of such problems.

Compositions of the corrosion products that form on magnesium alloys in an atmosphere vary from one location to another and from indoor to outdoor exposure. When humidity is high and a magnesium alloy has been coated or clad, local breakdown of the protective cladding/coating or film can promote pitting corrosion instead of general corrosion on the component.

In stagnant distilled water at room temperature, magnesium alloys rapidly form a protective film that prevents further corrosion. However, small amounts of dissolved salts in the water break down the film locally, leading to pitting corrosion. Dissolved oxygen plays no major role in the corrosion of magnesium alloys in fresh water or saline solutions, contrary to its effect in many other alloy systems. When agitation (erosion) destroys or depletes the surface film, corrosion can be significantly increased. The corrosion of magnesium alloys by pure water substantially increases as temperature increases.

Severe corrosion of magnesium alloys may occur in neutral salt solutions of metals such as copper, nickel, and iron. This occurs because salts are deposited on the surface and form active cathodic sites on the anodic magnesium alloy surface. Magnesium is rapidly attacked by all mineral acids, except hydrofluoric acid and chromic acid. However, pitting may occur in hydrofluoric acid solutions.

Organic compounds such as aliphatic and aromatic hydrocarbons, ketones, ethers, glycols, and higher alcohols are not corrosive to magnesium and its alloys. Ethanol causes slight attack, and anhydrous methanol causes severe attack. Water added to the methanol reduces the rate of attack. Pure halogenated organic compounds do not attack magnesium at ambient temperatures, but at elevated temperatures or if water is present, such compounds may cause severe corrosion. Although ethylene glycol solutions produce negligible attack of magnesium at room temperature, when the magnesium is used alone or connected to steel, a significant acceleration of corrosion attack can occur at higher temperatures (such as 115 *C, or 240 *F) unless inhibitors are used. In acidic foodstuffs such as fruit juices and carbonated beverages, attack of magnesium occurs at a slow but measurable rate.

Magnesium and its alloys are used at moderately elevated temperatures with no significant oxidation attack up to the temperatures at which the alloys can be used structurally. Magnesium alloys are usually creep strength, not oxidation, limited. Water vapor in air or in oxygen sharply increases the rates of oxidation of magnesium and its alloys. These rates increase with temperature.

Dry halogens cause little or no corrosion of magnesium at room or moderately elevated temperatures. The presence of moisture causes pronounced attack by chlorine, some attack by iodine and bromine, but no attack by fluorine. Wet chlorine, iodine, or bromine, below the dew point of any aqueous phase, causes severe attack of magnesium.

Dry, gaseous sulfur dioxide causes no attack at ordinary temperatures. If moisture is present, some corrosion may

Table 7 Magnesium Suitability for Testing in Various Substances

Source: Dow Chemical USA, Midland, MI

Chemical	Concentration, %	Service test warranted
Acetaldehyde	Any	No
Acetic acid	Any	No
Acetone	Any	Yes
Acetylene	100	Yes
Alcohol, butyl	100	Yes
Alcohol, ethyl	100	Yes
Alcohol, isopropyl	100	Yes
Alcohol, methyl	100	No
Alcohol, propyl	100	Yes
Ammonia (gas or liquid)	100	Yes
Ammonium salts (most)	Any	No
Ammonium hydroxide	Any	Yes
Aniline	100	Yes
Anthracene	100	Yes
Arsenates (most)	Any	Yes
Benzaldehyde	Any	No
Benzene	100	Yes
Bichromates	Any	Yes
Boric Acid	1–5	No
Brake Fluids (most)	100	Yes
Bromides (most)	Any	No
Bromobenzene	100	Yes
Butter	100	No
Butylphenols	100	Yes
Calcium arsenate	Any	Yes
Calcium carbonate	100	Yes
Calcium chloride	Any	No
Calcium hydroxide	100	Yes
Camphor	100	Yes
Carbon bisulfide	100	Yes
Carbon dioxide (dry)	100	Yes
Carbon monoxide	100	Yes
Carbon tetrachloride	100	Yes
Carbonated water	Any	No
Castor oil	100	Yes
Cellulose	100	Yes
Cement	100	Yes
Chlorides (most)	Any	No
Chlorine	100	No
Chlorobenzenes	100	Yes
Chloroform	100	Yes
Chlorophenols	Any	No
Chlorophenylphenol	100	Yes
Chromates (most)	Any	Yes
Chromic acid	Any	Yes
Citronella oil	100	Yes
Cod liver oil (crude)	...	Yes
Copals	100	Yes
Coumarin	100	Yes
Cresol	100	Yes
Cyanides (most)	Any	Yes
Dichlorohydrin	100	Yes
Dichlorophenol	100	Yes
Dichromates (see bichromates)		
Diethanolamine	100	Yes
Diethyl aniline	100	Yes
Diethyl benzene	100	Yes
Diethylene glycol solutions	Any	Yes, may need inhibitors
Diphenyl	100	Yes
Diphenylamine	100	Yes
Diphenylmethane	100	Yes
Diphenyl oxide	100	Yes
Dipropylene glycol	100	Yes
Divinylbenzene	100	Yes
Dry cleaning fluids	100	Yes
Ethers	100	Yes
Ethanolamine (mono)	100	Yes
Ethyl acetate	100	Yes
Ethyl benzene	100	Yes
Ethyl bromide	100	No
Ethylcellulose	100	Yes
Ethyl chloride	100	Yes
Ethyl salicylate	100	Yes
Ethylene (gas)	100	Yes
Ethylene dibromide	100	Yes
Ethylene glycol solutions	Any	Yes, may need inhibitors
Fats, cooking (acid-free)	100	Yes
Fatty acids	Any	No
Ferric chloride	Any	No
Fluorides (most)	Any	Yes
Fluosilicic acid	Any	No
Formaldehyde	Any	Yes
Fruit juices and acids	Any	No
Fuel oil	100	Yes
Gasohol (10% ethanol)	100	Yes, if inhibited
Gasohol (10% methanol)	100	Yes, if inhibited
Gasoline (lead-free)	100	Yes, if inhibited
Gasoline (leaded)	100	Yes, if inhibited
Gelatine	Any	Yes
Glycerine C.P.	100	Yes
Grease (acid-free)	100	Yes
Heavy metal salts (most)	Any	No
Hexamine	3	Yes
Hydrochloric acid	Any	No
Hydrofluoric acid	5–60	yes
Hydrogen peroxide	Any	No
Hydrogen sulfide	100	Yes
Iodides	Any	No
Iodine crystals (dry)	100	Yes
Isopropyl acetate	100	Yes
Isopropyl benzene	100	Yes
Isopropyl bromide	Any	No
Kerosene	100	Yes
Lanolin	100	Yes
Lard	100	Yes
Lead arsenate	Any	Yes
Lead oxide	Any	No
Linseed oil	100	Yes
Magnesium arsenate	Any	Yes
Magnesium carbonate	100	Yes
Magnesium chloride	Any	No
Mercury salts	Any	No
Methane (gas)	100	Yes
Methyl bromide	Any	No
Methyl cellulose	100	Yes
Methyl chloride	100	Yes
Methylene chloride	100	Yes
Methyl salicylate	100	Yes
Milk (fresh and sour)	100	No
Mineral acids	Any	No
Monobromobenzene	100	Yes
Monochlorobenzene	100	Yes
Naphtha	100	Yes
Naphthalene	100	Yes
Nicotine sulfate	40	Yes
Nitrates (all)	Any	No
Nitrous gases	100	No
Nitric acid	Any	No
Nitroglycerin	Any	No
Oil, animal (acid- and chloride-free)	Any	Yes
Oil, mineral (chloride-free)	100	Yes
Oil, vegetable (chloride-free)	100	Yes
Oleic acid	100	Yes
Olive oil	100	Yes
Organic acids (most)	Any	No
Orthochlorophenol	100	No
Orthodichlorobenzene	100	Yes
Orthophenylphenol	100	Yes
Oxygen	100	Yes
Paraphenylphenol	100	Yes
Paradichlorobenzene	100	Yes
Pentachlorophenol	100	Yes
Perchloroethylene	100	Yes
Permanganates (most)	Any	Yes
Phenol	100	Yes
Phenyl ethyl acetate	100	Yes
Phenylphenols	100	Yes
Phosphates (most)	Any	Yes
Phosphoric acid	Any	No
Polypropylene glycols	100	Yes
Potassium fluoride	Any	Yes
Potassium hydroxide	Any	Yes
Potassium nitrite	Any	No
Potassium permanganate	Any	Yes
Propylene glycol U.S.P.	100	Yes
Propylene oxide	100	Yes, may need inhibitors
Pyridine (acid free)	100	Yes
Pyrogallol	Any	No
Rubber and rubber cements	100	Yes
Seawater	100	No
Sodium bromate	Any	No
Sodium bromide	Any	No
Sodium carbonate	Any	Yes
Sodium chloride	Any	No
Sodium cyanide	Any	Yes
Sodium dichromate	Any	Yes
Sodium fluoride	Any	Yes
Sodium hydroxide	Any	Yes
Sodium phosphate (tribasic)	Any	Yes
Sodium silicate	Any	Yes
Sodium sulfide	3	Yes
Sodium tetraborate	3	Yes
Steam	100	No
Stearic acid (dry)	100	Yes
Styrene polymer	100	Yes
Sugar solutions (acid-free)	Any	Yes
Sulfates (most)	Any	No
Sulfur	100	Yes
Sulfur dioxide (dry)	100	Yes
Sulfur chloride	Any	No
Sulfuric acid	Any	No
Sulfurous acid	Any	No
Tannic acid	3	No
Tanning solutions	Any	No
Tar, crude and its fractions	100	Yes
Tartaric acid	Any	No
Tetrahydronaphthalene	100	Yes
Titanium tetrachloride	100	Yes
Toluene (toluol)	100	Yes
Trichlorbenzene	100	Yes
Trichloroethylene	100	Yes
Trichlorophenol	100	Yes
Tung oil	100	Yes
Turpentine	100	Yes
Urea	100	Yes
Urea in aqueous solution (cold)	Any	Yes
Urea in aqueous solution (warm)	Any	No
Vinegar	Any	No
Vinylidine chloride	100	Yes
Vinyl toluene	100	Yes
Water, boiling	100	No
Water, distilled	100	Yes
Water, rain	100	Yes
Waxes (acid-free)	100	Yes
Xylol	100	Yes

occur. Wet sulfur dioxide gas is severely corrosive to magnesium. Ammonia (wet or dry) causes no attack at ambient temperatures; dry, gaseous sulfur dioxide causes no attack either. Some corrosion by sulfur dioxide may occur if water is present.

Although a great deal is known about the electrochemistry of magnesium and its alloys, very little information has been published concerning the role of alloying elements on corrosion resistance.

Effect of Alloying Elements

A study of the effects of 14 elements on the saltwater corrosion performance of magnesium in binary alloys showed the following trends. Aluminum, manganese, silicon, tin, lead, thorium, zirconium, and cerium had little or no deleterious effect on the basic saltwater corrosion performance of magnesium at levels either up to and exceeding their limits of solubility in magnesium or up to a maximum of 5%. Cadmium, zinc, calcium, and silver had mild-to-moderate accelerating effects on corrosion rates, whereas iron, cobalt, nickel, and copper had extremely deleterious effects on saltwater corrosion. The tolerances for these latter elements is a function of the basic alloy composition and the composition of the corroding medium.

No information is available on the effects of alloy elements on the elevated temperature (dry corrosion) oxidation resistance of magnesium. It seems probable that aluminum will be beneficial, but high-aluminum-content alloys are not preferred for elevated temperature structural applications, simply because other alloys are stronger.

Coatings

It is a common practice to protect the surface of magnesium and its alloys. They are protected by a wide range of chemical and anodic treatments. Proper cleaning and surface preparation are important steps to achieve optimum, lasting protection. Dichromate, chrome manganate, and chrome pickle treatments may be used. These chemical processes generally involve pickling and conversion of the oxide surface compounds by dipping in the appropriate solutions, which clean and passivate the surface through enhanced formation of magnesium hydroxide and a chromium compound. These films have limited protective value, but form a good base on which to subsequently apply organic coatings.

Anodizing by galvanic or applied current provides alternate protection. A hard, abrasion-resistant and corrosion-resistant surface layer is created. The anodized films are porous, just as in anodizing of aluminum; they may be sealed by immersion treatments in an appropriate solution, followed by draining and drying. Organic resins may be applied instead to seal the anodized surface. Epoxy resins are one type of organic used. Magnesium also may be protected by painting or plating.

Selection for Corrosion Resistance

In general, one does not think of selecting magnesium alloys for corrosion resistance in the same way that one thinks of the passive or more noble structural materials—copper, nickel, titanium (and their alloys), as well as stainless steel or aluminum. There is little to offer in the way of advice relative to alloy composition. Environmental avoidance, principally by the use of appropriate coatings, is the best way to ensure optimum corrosion resistance for the particular application. For maximum protection, high-purity alloys as well as inhibitors (if possible) in the environment will complement the selected protective coating.

Lead and Lead Alloys

The widespread and satisfactory use of lead and some lead alloys results from its ability to resist attack by corrosive chemicals, by a variety of atmospheres, and in underground applications either as a protective covering or as a distribution device containing a variety of highly aggressive chemicals. There is evidence of the use of buried lead pipe as early as ancient Egypt. An early corrosion resistance application during more recent times involved the use of lead in containers for sulfuric acid systems. Table 8 gives the corrosion behavior of lead in commonly used chemicals.

Corrosion Resistance

The corrosion resistance of lead is based on its ability to readily form a tenacious coating of a reaction product. This then becomes a protective coating. In principle, this process is similar to the surface protection that naturally forms on stainless steels and on certain aluminum alloys. Protective coatings on lead may form as the result of exposure to sulfates, oxides, carbonates, chromates, or chemical complexes. In aqueous phases, solubility of the corrosion product must be low enough to depress solution of the protective film formed on the lead. Also, where lead is used for transporting or for holding materials, the degree of turbulence within the system should be considered in construction designs so as to reduce the erosive effects on the protective coatings.

Industrial Applications

Beyond the common and expected use of lead as shielding for X-rays and nuclear installations and for storage battery grids, there are applications in which its corrosion resistance qualities

Table 8 Chemical Resistance of Lead to Various Materials

Source: *Lead for Corrosion Resistant Applications: A Guide,* Lead Industries Association, Inc., New York

Material	Behavior
Acetic acid	Lead is resistant to cold glacial acetic acid and acetic anhydride and is used as a material for making storage vessels. Lead is not recommended with lower concentrations because of the accelerating effect on corrosion of velocity, temperature and attack at the liquid-air interface
Acetone	Lead is resistant and is used in equipment for its manufacture
Acetophenone	Lead equipment is used in manufacture and storage
Acetylene	Lead is resistant to acetylene except when the gas is moist and contains hydrogen phosphide
Acetylene tetrachloride	Lead is satisfactory for lining feed tanks
Adipic acid	Lead-lined digesters are used in manufacture
Alcohol, ethyl	No effect on lead
Alcohol, methyl	No effect on lead
Aluminum chloride	Lead is quite resistant to aluminum chloride at concentrations up to 10%. It is not recommended at higher concentrations. It is used to some extent in equipment for the manufacture of aluminum chloride
Aluminum sulfate or alum	Lead is used satisfactorily in manufacture and handling of liquid alum
Ammonia	Lead is resistant to the dry gas and to anhydrous liquid ammonia
Ammonium azide	No significant effect on lead
Ammonium bifluoride	Lead can be used satisfactorily
Ammonium chloride	Lead may be used at ambient temperatures with concentrations up to 10%
Ammonium fluoride	Lead has acceptable resistance to ammonium fluoride at concentrations up to 20%. It is not recommended for use at high temperatures or in the presence of free ammonia
Ammonium fluosilicate	Lead is sometimes used for valves and fittings
Ammonium hydroxide	Lead is satisfactory for use in the liquid or gas phases at virtually all temperatures and concentrations
Ammonium hydroxylamine	Lead is satisfactorily used in hydrolysis
Ammonium phosphate	Lead is fairly resistant to ammonium phosphate and is used in the manufacture of ammonium phosphate fertilizer
Ammonium sulfate	Lead may be satisfactorily employed in the manufacture and handling of ammonium sulfate
Antimony chloride	Lead is corroded but can be used with comparative economy for chlorinating the trichloride to the pentachloride
Arsenic acid	Lead is quite resistant to dilute arsenic acid. Lead salts may form, but pipe life is satisfactory with periodic cleaning
Barium sulfide	Lead tanks are used in handling solutions prior to precipitation of barium sulfide
Benzol	Pure benzol has little or no effect on lead
Benzyl chloride	Lead is often used for storage equipment
Benzylphenol	Manufactured in lead-lined vessels at temperatures up to 40 °C (104 °F)
Bleach solution	Lead is satisfactory for an aqueous bleach solution of hydrogen peroxide and trisodium phosphate
Boric acid	Lead is used satisfactorily in its manufacture
Brine	See Sodium chloride
Bromine	When cold and acid free, lead may be used for shipping containers
Cadmium sulfate	Lead is widely employed for lining plating tanks
Calcium acid phosphate	Lead can be used over a wide range of concentrations and temperatures
Calcium carbonate	Lead is resistant to all concentrations found in natural waters
Calcium disulfide	Lead is satisfactory
Calcium hydroxide	Lead is not recommended for use in calcium hydroxide. Its presence in "green" cement corrodes lead in presence of moisture and oxygen
Calcium pyridine sulfonate	If sulfuric acid is present, lead can be used
Carbon dioxide	Lead is used in acid-carbonate systems for generating CO_2
Carbon tetrachloride	Lead is used at ambient temperatures
Castor oil in acid	Lead is used for piping and valves
Chlorinated hydrocarbons	Lead can satisfactorily be used if inhibitors are present
Chlorinated polyvinyl chloride	Lead used throughout manufacture
Chlorination processes	Lead is slowly corroded at the temperatures normally used, but has satisfactory life and good economy when compared with other common metals
Chlorine	Lead is resistant to dry chlorine and may be used with moist chlorine up to about 38 °C (100 °F)
Chloroacetic acid	Lead has only fair resistance, but is satisfactory for dilute solutions containing carbon tetrachloride
Chlorobenzene	Lead is satisfactory in solutions of chlorobenzene, sulfur dioxide and water
Chlorobromomethane	When dry (less than 0.02% H_2O) practically noncorrosive to lead
Chromic acid	Lead may be used at fairly high concentrations. Used as anodes, heating coils, and tank linings for chromium plating installations. Proprietary lead alloys have been developed for better corrosion resistance with high speed plating solutions
Coal tar	Lead is used in the refining and recovery of many by-products
Concrete, cement or mortar	When "green," free lime is present and it will attack lead. If calcium chloride has been added, the attack will be accelerated. Applying asphalt coating on lead is recommended to prevent such corrosion. On aging, the free lime is converted to calcium carbonate, at which time corrosion will cease
Copper sulfate	Lead is used for anodes and tank linings in electrorefining, electroplating, and electroforming equipment and is preferred for acid solutions
Dibutyl thiodiglycolate	Part of manufacturing process conducted in lead-lined vessels
Dihydroxydiphenyl sulfone	Lead cooling coils and bonded lead-lined pressure vessels used in manufacture
Electrogalvanizing	Lead equipment is often employed
Ether	Little or no effect on lead. Lead used in its manufacture
Fatty acids	Lead can be used, but it will corrode slowly in presence of oxygen
Ferric chloride	Lead is not recommended
Ferric sulfate	Lead is resistant over a wide range of concentrations and temperatures. Used in its manufacture
Ferrous chloride	Lead is recommended
Ferrous sulfate	Lead is suitable for tank linings and coils in production and use
Fluorolubes	Shipped in lead-lined pails to prevent contamination and discoloration
Formaldehyde (and formic acid)	Lead is resistant to formaldehyde of 100% concentration, but is not recommended for lower concentrations. Its reaction is similar to that with acetic acid
Hexachlorbutadiene	Is highly corrosive to all metals except lead. Lead used throughout manufacture at temperatures up to 205 °C (400 °F)
Hexachlorethane	Lead-lined equipment is used for chlorination vessel and crystallizing basins up to 60% concentration and 136 °C (275 °F)
Hydrochloric acid	Use of lead is not generally recommended, but it has been used with some corrosion in concentrations up to 30% at ambient temperatures and 20% at 100 °C (212 °F). Antimonial lead shows better resistance than ordinary lead
Hydrocyanic acid	Lead is used in its manufacture
Hydrofluoric acid	Lead is commonly used and has fair resistance to dilute acid, under 65% strength at room temperature
Hydrogen chloride (anhydrous hydrochloric acid)	Little effect on lead
Hydrogen peroxide	A 50% by weight, aqueous solution of hydrogen peroxide has been found to cause pitting, with a penetration in excess of 50 mpy. The lead may catalyze the breakdown of hydrogen peroxide
Magnesium chloride	Lead is fairly resistant to magnesium chloride at concentrations up to 10%. Otherwise, it is not recommended

(Continued)

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Table 8 (continued)

Material	Behavior
Cellophane spinning bath solutions	Lead equipment is used extensively
Mercuric sulfate	Highly oxidizing, but lead in general has good resistance to most acid sulfate conditions at room temperature
Mixed acids	Lead can be used with some mixtures of sulfuric acid and nitric acid. Lead used for tank linings for matte finishing brass with 50% sulfuric-50% nitric acid solution
Naphthalene	No effect on lead
Nickel sulfate and nickel plating solutions	Lead commonly used for tank linings and heating coils
Nitro-benzol and nitro-chlor-benzol	Corrosive to lead
Nitrocellulose	Lead widely used in all rayon manufacturing processes
Nitroglycerine	Lead used to handle spent acid from manufacturing process
Nitrosyl-sulfuric acid	Action on lead is least at specific gravity of about 1.5 to 1.6. Close control thus minimizes corrosion
Organic acids	Lead is generally not recommended, although it may be fairly resistant to organic acids if free sulfuric acid is present
Oxalic-sulfuric acids	Lead is satisfactory with oxalic acid containing 1% free sulfuric acid in all concentrations from 5 to 50% and all temperatures from cold to boiling
Oxygen	Dry gas merely tarnishes lead
Pentachlorethane	Lead used in manufacture and storage at temperatures up to 80 °C (176 °F)
Phenol	Lead may be used satisfactorily
Phosphoric acid	Lead due to the formation of protective films, may be used with concentrations up to 80% below 93 °C (200 °F). Impure acid has even less effect on lead and can be used up to 85% concentration
Phosphorus oxychloride	Storage tanks are constructed of lead or bonded lead. Lead piping, coils and receivers also used in its manufacture. Commonly shipped in lead carboys, lead-lined drums, or lead-lined tank trucks
Photographic solutions	Lead is generally satisfactory
Potassium hydroxide	Lead is satisfactory up to 50% concentration and temperatures to 60 °C (140 °F)
Potassium metabisulphite	The preferred material of construction is lead and lead-lined steel. Evaporated in lead-lined tanks at 71 °C (160 °F)
Potassium permanganate	Attacks lead; not recommended
Pyridine	Does not affect lead which is used for vacuum distilling equipment
Silica gel	Lead is used for tank linings, pipes, and valves in the process of washing silica gel
Silicates	These form protective films on lead
Sodium bifluoride	Successfully handled in lead
Sodium bisulfate	Lead is resistant to sodium bisulfate over a wide range of temperatures and concentrations
Sodium bisulfite	Lead may be used with a wide range of concentrations and temperatures
Sodium carbonate	Dilute solutions do not affect lead. Not recommended for solutions over 25% at temperatures above 66 °C (150 °F)
Magnesium sulfate	Lead is resistant over a wide range of concentrations and temperatures
Sodium chloride	Lead satisfactory for dilute solutions at ordinary temperatures. Sea water and brine are commonly handled in lead or antimonial lead
Sodium hydrosulfite	Lead may be used satisfactorily
Sodium hydroxide	Lead can be used with concentrations up to 30% and temperatures to 25 °C (77 °F). Strong solutions attack lead rapidly
Sodium hyposulfite	Lead can be used satisfactorily
Sodium silicate	No significant corrosive effect on lead
Sodium sulfate	Lead can be used satisfactorily with solutions up to 10% concentration at boiling
Sodium sulfide	Lead can be used at temperatures up to 100 °C (212 °F)
Sodium sulfite	Lead can be used with solutions up to 20% concentration at 25 °C (77 °F). Used in its manufacture
Sulfur chloride	Has little effect on lead
Sulfur dioxide	Has little effect on lead when dry and can be used moist up to about 200 °C (392 °F)
Sulfur trioxide	Can be used satisfactorily with lead up to 150 °C (302 °F)
Sulfuric acid	Lead is the standard material for handling this acid. It can be used with concentrations up to 96% at room temperature and 85% up to 220 °C (428 °F). It is sometimes used satisfactorily even up to 250 °C (482 °F)
Sulfurous acid	Lead is satisfactory up to about 220 °C (428 °F)
Tannic acid	Lead behavior is similar to that for acetic acid
Tartaric acid	Lead behavior is similar to that for acetic acid
Tetrachloroethane	Bonded lead reaction tower and other lead-lined equipment used in manufacture
Thionyl chloride	Lead is satisfactory at temperatures up to 150 °C (302 °F)
Titanium sulfate	Solutions can be handled in lead
Titanium tetrachloride	Lead gaskets used in pipe flanges
Urea	Lead-lined autoclave and stills used in manufacture at temperatures up to 190 °C (374 °F)
Water, distilled	Has no effect in the absence of dissolved CO_2 and oxygen. Not generally recommended for such use
Water, natural	Usually has no effect on lead because of protective coating formed from dissolved salts. Very soft waters or those of peaty origin may dissolve lead slightly. Such action can be prevented by treatment of the waters with lime or sodium silicate to raise the "hardness"
Wood	Most wood has little or no corrosive effect on lead. A few instances of corrosion by wood containing organic acids, such as green oak, have been reported. Wood to be lined with lead should be inspected for presence of borers
Zinc chloride	Lead can be used satisfactorily
Zinc hydrosulfite	Manufactured in lead-lined tanks using lead cooling coils
Zinc sulfate	Lead preferred when solution is acid. Employed for its manufacture and use

are of primary importance. Examples include chemical-industry piping, tanks, tank linings, valves, and fittings. Until a generation ago, the construction industry frequently used the material in roofing gutters, plumbing, shower pans, drain pipes, and flashings. Such applications are constantly encountered in older structures. More recently, telephone and power transmission equipment employed lead sheathing on overhead poles and in both underwater and overhead installations. To a large extent, contemporary engineered materials have replaced the metal in most of these applications. However, lead is still used in the electronics industry and in conjunction with certain types of acids.

Corrosion in Acids

Lead is commercially used for resistance to sulfuric, sulfurous, chromic, and phosphoric acids. It has somewhat poorer, although often adequate, corrosion resistance to hydrochloric and hydrofluoric acids. Lead has excellent resistance to neutral solutions in which carbonates help to form the protective surface. It also has fair resistance to most alkaline solutions.

Lead has very little susceptibility to passivation in oxidizing acids. However, it is very stable in those media in which soluble

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corrosion products of lead can form. This generalization is especially true with solutions containing sulfate ion, such as sulfuric acid or solutions of its salts. By contrast, lead is not stable in nitric and acetic acids, nor in alkalis.

Lead resists sulfurous, cold phosphoric, chromic, and hydrofluoric acids. In hydrofluoric acid, lead is stable only at an acid concentration of 10%, and this is at comparatively low temperatures. In mixtures of sulfuric and hydrochloric acids, lead is much more stable than in hydrochloric acid alone. With the exception of cold nitric acid at high concentrations, the metal does not resist nitric acid. Lead corrodes rapidly in acetic and formic acids.

The corrosion rate in acids increases rapidly in the presence of oxygen and also in oxygen in combination with soft waters, such as rain and distilled water. Corrosion increases at a rate approximately proportional to the oxygen content of the water.

Atmospheric and Underground Corrosion

Lead is highly resistant in atmospheric exposures. It is frequently preferred over such metals as iron, zinc, and nickel in industrial atmospheres strongly contaminated with sulfur compounds such as H_2S, SO_2, or H_2SO_4.

In most of its forms, lead exhibits consistent durability in all types of atmospheres, including rural, industrial, and marine. In rural settings, the only important environmental factors that affect corrosion are the level of humidity and the amounts of rainfall and air flow. Near the sea, saline air exerts a strong effect on the corrosion rate. In industrial atmospheres, sulfur oxides and minerals in solid emissions may change the pattern of corrosion. However, the protective films that form on lead from exposure to industrial and marine atmospheres are so effective that the extent of the corrosion is usually insignificant.

Although some soils are more corrosive than others, severe corrosion of lead in underground service is rare. In general, the rate of corrosion *decreases* in soil according to the following order—muck, cinders, sand, and clay. When either lime or fresh concrete is present in the envelope of soil, water seepage and the presence of oxygen increase the corrosion rate. This is especially true for underground installations, but also for aboveground structures if the soil factor is discounted. To prevent corrosion under these conditions, lead components are frequently coated with asphalt, which provides protection during the curing of the concrete.

Corrosion in Waters

Distilled water that is free of oxygen and CO_2 does not attack lead. Lead steam coils that handle pure water condensate are not severely corroded if all condensate is returned to the boiler with only negligible amounts of makeup water. If appreciable amounts are used, corrosion from dissolved oxygen can become severe.

In general, the corrosion rate of lead in natural waters depends on water hardness, as caused by calcium and magnesium salts. Moderate amounts of these salts form protective films on the lead that adequately protect it against corrosive attack. Silicate salts present in the water increase both the hardness and the protective value of the film. In contrast, nitrate and chloride ions either interfere with the formation of the protective film or penetrate it. Thus, they increase corrosion. Lead also corrodes severely in underground waters containing either organic acids or large amounts of carbonic acid.

Grades of Lead

For corrosion resistance, lead is usually chosen from the ASTM grades known as acid-copper lead. In some instances, lead alloys are chosen (e.g., alloys such as lead with 0.05% tellurium and lead-antinomy alloys). Lead with 6% antinomy is probably the most common. Data show that corrosion rates for these alloys are not significantly different from commercially pure lead. As a rule, these alloys are used to gain strength over that offered by pure lead.

Disadvantages

Despite the overall excellent corrosion-resisting properties of lead, the metal itself presents usage limitations in at least three areas. First, its strength and hardness are very low, as contrasted with that of stainless steel and other corrosion-resisting metals. Second, lead is extremely heavy compared to steel. Consequently, underground applications lend themselves more readily than aerospace. Third, there is the factor of eye appeal. After it gains its protective coating, the metal simply does not have an appearance that is acceptable for applications demanding a degree of attractiveness.

Zinc and Zinc Alloys

Zinc is one of two metals that are used extensively in protective coatings on steel and sometimes on aluminum. Its excellent protective properties, along with its relatively high corrosion resistance in a natural environment, ensure that the metal will have wide industrial application. When used as a coating, it produces an anodic coating that not only protects mechanically by shielding, but also electrochemically. Zinc and its alloys are used extensively as galvanic anodes. Large amounts of zinc are used to produce copper-zinc (brass) alloys. However, zinc-base alloys find few applications. The susceptibility of zinc to passivation is insignificant, although it can be easily passivated in chromate solutions. Table 9 contains corrosion-rate data for zinc in contact with various chemicals.

Atmospheric Corrosion

The resistance of zinc to corrosion in all types of atmospheres is the property most broadly exploited. In wrought zinc products, this attribute is capitalized on throughout service life. On galvanized steel, the initial corrosion resistance of zinc continues well into the service life of the part. When the underlying steel is finally exposed, the ability of zinc to protect sacrificially continues.

Although several factors contribute to the rate at which zinc corrodes in outdoor exposure, two of the principal governing factors are the frequency and duration of moisture contact and the rate of drying in rural atmospheres. Near industrial sites, these conditions are aggravated by pollutants, usually acids. Thus, the rate of attack depends largely on the degree of acidity in the atmosphere. The most harmful atmospheric conditions are those in which frequent wetting of the metal results from dew, rain, and fog, especially if the moisture has a high acidic content.

Aqueous Corrosion

Temperature, gases in waters, and water hardness, singly or collectively, influence the corrosion rate (or corrosion resistance) of zinc. The corrosion rate of zinc increases rapidly between room temperature and approximately 60 °C (140 °F). At this point, there is a distinct turnaround, and the rate decreases markedly at 100 °C (212 °F). Under comparable circumstances, the corrosion rate of zinc in water is less than that of iron. Thus, zinc coatings are widely used in contact with water. As with other common metals, the rate of attack varies greatly with variations in exposure conditions. With zinc, the corrosion rate depends on temperature, pH, and oxygen concentration. It increases with increasing oxygen and carbon dioxide content.

Under conditions where the oxygen content cannot be replaced as quickly as it is consumed by the corrosion process, such as in stagnant water, zinc is attacked rapidly in localized areas, thereby creating pits. As more oxygen is made available, corrosion becomes more uniform. With further increase in oxygen content of the water, the corrosion rate increases. For example, when thin films of moisture condense on a zinc surface, the concurrent rapid supply of oxygen at the corroding surface has a decided accelerating effect on the corrosion rate.

Both this and the stagnant water types of attack can be minimized by the use of chromate films. Experimentation has shown that, with test pieces immersed in water through which oxygen was bubbled, corrosion occurred about eight times as fast as with specimens in water that was boiled to remove gases and then cooled out of contact with air.

Natural Fresh Waters

The corrosion rate of zinc in natural fresh waters depends on the composition of the water, which can vary over a wide range. Water hardness is an important consideration. Hard waters usually deposit protective films on zinc surfaces. Thus, they are less corrosive than soft waters. As an example, weight losses ranging from 3 mg^2/dm^2/day in hard water to as much as 27 mg^2/dm^2/day in distilled water have been observed with high-grade zinc.

Dissolved Salts, Acids, and Bases

Zinc should not be considered for use in strong acids and alkalis. Even dilute acids accelerate corrosion rates of zinc beyond the limits of usefulness. Alkaline solutions of moderate strength are less corrosive than corresponding concentrations of acids, but are still sufficiently corrosive so as to eliminate zinc as a candidate material.

The addition of iron, nickel, copper, and noble metals, because of their low hydrogen overvoltage, considerably increase corrosion of zinc in acids.

In neutral solutions, zinc corrodes basically by oxygen depolarization, and the impurities in the zinc do not appreciably change its corrosion behavior. Zinc is not resistant to alkalis, because zinc oxide is amphoteric and forms zincates in solution, such as Na_2ZnO_2.

Nonaqueous Liquids and Gases

Many organic liquids that are nearly neutral in pH and substantially free from water do not attack zinc. Because of this, zinc and zinc-coated products are commonly used with gasoline, glycerine, and inhibited trichlorethylene. The presence of free water may cause local corrosion, because of the lack of access to oxygen. With water present, zinc may function as a catalyst in the decomposition of solutions like trichlorethylene, thereby resulting in acid attack. Some organic compounds, such as low-grade glycerine, attack zinc.

Zinc may safely come in contact with most common gases at normal temperatures, provided water is not present. Moisture content stimulates attack. Dry chlorine does not affect zinc, and hydrogen sulfide is also harmless, because insoluble zinc sulfide is formed. On the other hand, sulfur dioxide and chlorides have a corrosive effect because water-soluble and hygroscopic salts are formed.

Food-Processing Applications

Zinc and zinc coatings are regularly avoided by the food-processing industry simply because zinc is not sufficiently stable in these environments. Moreover, zinc salts are toxic.

Corrosion Inhibitors

When zinc is in contact with water in a closed system, inhibitors are commonly used to minimize corrosion. Inhibitors include sodium dichromate, sodium silicate, and borax. For most purposes, the adjustment of pH to the mildly alkaline range and also the addition of sodium dichromate to the system is the preferred technique of corrosion control. An insufficient amount of inhibitor may result in pitting corrosion.

Table 9 Resistance of Zinc and Zinc Coatings to Corrosion in Chemical Environments

Chemicals and simple mixtures are listed alphabetically, with the main chemical of the mixture listed first. Chemical specialty mixtures, which often contain a number of components, have been placed under application headings (e.g., Agricultural chemicals, Building materials). There was little uniformity in test conditions among the various investigations from which these data were compiled. For example, test temperatures ranged from below zero to the boiling point, and time of immersion from a few hours to several months. The test procedures also included exposure to vapors and partial or total immersion in the solutions. The test conditions adopted in each investigation were no doubt dictated by specific objectives, but in comparing results of the tests, the possible influence of the test variables should be taken into account.
Source: *Zinc: Its Corrosion Resistance,* International Lead Zinc Research Organization, Inc., New York, 1983

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
Acetic acid											
0.1 g/L in air		(L) In vapors	30	86	8 days	...	...	69.0	14.0		1
0.005 ppm in air over water	99.95%Zn	(L) In vapors	30	86	21 days	...	...	0.91	0.2	100% RH	2
0.05 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	2.14	0.4	100% RH	2
0.5 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	25.9	5.2	100% RH	2
2.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	118.0	23.6	100% RH	2
3.5 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	143.7	28.8	100% RH	2
5.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	193.0	38.6	100% RH	2
20.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	55.2	11.0	100% RH	2
35.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	35.8	7.2	100% RH	2
50.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	38.8	7.7	100% RH	2
500.0 ppm in air over water	99.95% Zn	(L) In vapors	30	86	21 days	...	...	85.6	17.1	100% RH	2
1% in water	99.95% Zn	(L) In vapors	30	86	6 days	...	...	218.1	43.6	100% RH	2
0.5% in sat'd sodium acetate	99.95% Zn	(L) In vapors	30	86	42 days	...	...	5.52	1.1	72% RH	2
Water solution, pH 3.8	Galv.	(L) In vapors	Room		8 days	...	...	8.0	1.6	100% RH	3
2.1% solution	Galv. steel	(L) In vapors	Room		30 days	...	...	26.5(c)	5.4		4
								13.3(d)	2.7		
								5.4(e)	1.1		
								3.0(f)	0.6		
5.1% solution	Galv. steel	(L) In vapors	Room		30 days	...	...	10.1(c)	2.0		4
								4.6(d)	0.9		
								1.2(e)	0.2		
								2.9(f)	0.6		
6% solution		(L) Immersion	30	86	2 days	None	None	3 050.0	610.0		5
6% solution		(L) Immersion	30	86	2 days	15–20 air bubbles per min	...	3 650.0	730.0		5
Acetone											
CP		(L) In vapors	Boiling		1 month	...	...	0.0	0.0		1
CP		(L) Immersion	Room		6 months	None	None	0.004	<0.1		1
CP + formic acid equiv. to 0.10 mg KOH/g	Sheet	(L) Partial immersion	30	86	7 days	None	None	0.1	<0.1		6
CP + 5% water	Sheet	(L) Partial immersion	30	86	7 days	None	None	0.1	<0.1		6
Agricultural chemicals											
Ammonium sulfamate	Sheet	(F) Immersion	15–40	60–100	98 days	...	...	15.0	3.0		1
Blue Amate Brush Killer	Sheet	(F) Immersion	15–40	60–100	112 days	Yes	Yes	4.7	1.0		1
Esteron Brush Killer (2–4D + 2,4,5–T1 gal/100 gal water	Sheet	(F) Immersion	15–32	60–90	119 days	...	...	18.5	4.0		1
Ammonium sulfate	Galv.	(L) Alternate humidity, weekly cycle forced-air circulation 24 h, 100% RH (1), 24 h, dry air (2). Repeat (1) and (2), then 8 h, 100% RH, 64 h dry air	...	...	121 days	...	...	...	10.0	Zinc stripped	7
Nitrolime	Galv.	As above	...	...	121 days	...	...	...	12.0	Zinc stripped	7
300 g/L $CuSO_4 \cdot 5H_2O$	Galv.	As above	...	...	121 days	...	...	...	3.0	Zinc partly stripped	7
280 g/L $CoSO_4 \cdot 5H_2O$	Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc penetrated locally	7
Potassium chloride (com.)	Galv.	As above	...	...	121 days	...	...	...	4.0	Zinc partly stripped	7
Superphosphate	Galv.	As above	...	...	121 days	...	...	...	0.0		7
Super compound	Galv.	As above	...	...	121 days	...	...	...	0.0		7
Super compound + small amount of copper sulfate	Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc penetrated locally	7
Super compound + small amount of cobalt sulfate	Galv.	As above	...	...	121 days	...	...	...	0.0		7

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium			Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Agricultural lime			Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc not penetrated	7
Burnt lime			Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc not penetrated	7
Basic slag			Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc not penetrated	7
Bone meal			Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc not penetrated	7
Phosphorized Pollard			Galv.	As above	...	...	121 days	...	...	...	0.0	Zinc not penetrated	7
Damp granular fertilizers													
Type	Components	Percent water											
11–48–0	$NH_4H_2PO_4$, $(NH_4)_2HPO_4$	5.41	Sp.H.G.(1)	(L) Immersed	60	140	33 days	Repacked with fresh water once a week		80.0	16.0		8
11–48–0	$NH_4H_2PO_4$, $(NH_4)H_2PO_4$	5.41	Die-cast AG-40A(2)	(L) Immersed	60	140	33 days			45.9	10.0	Galv. steel, failed in all mixtures	8
12–12–12	11–48–0, $(NH_4)_2SO_4$, KCl	6.18	(1)	(L) Immersed	60	140	33 days			1 005.0	201.0		8
12–12–12	11–48–0, $(NH_4)_2SO_4$, KCl	6.18	(2)	(L) Immersed	60	140	33 days			1 460.0	318.0		8
13–16–10	11–48–0, $(NH_4)_2SO_4$, KCl	6.68	(1)	(L) Immersed	60	140	33 days			50.0	10.0		8
13–16–10	11–48–0, $(NH_4)_2SO_4$, KCl	6.68	(2)	(L) Immersed	60	140	33 days			55.0	12.0		8
16–20–0	11–48–0 $(NH_4)_2SO_4$	4.10	(1)	(L) Immersed	60	140	33 days			35.0	7.0		8
16–20–0	11–48–0, $(NH_4)_2SO_4$	4.10	(2)	(L) Immersed	60	140	33 days			156.0	34.0		8
35.5–0–0	NH_4NO_3	3.54	(1)	(L) Immersed	60	140	33 days			2 290.0	458.0		8
35.5–0–0	NH_4NO_3	3.54	(2)	(L) Immersed	60	140	33 days			788.0	172.0		8
21–0–0	$(NH_4)_2SO_4$	2.50	(1)	(L) Immersed	60	140	33 days			22.0	4.4		8
21–0–0	$(NH_4)_2SO_4$	2.50	(2)	(L) Immersed	60	140	33 days			6.9	1.5		8
(a) 11–48–0		5.4	Sp.H.G.(1)	(L) Immersion	Room		11 days			37.5	7.5	Four changes of moist fertilizer in all tests	8
(a) 11–48–0		5.4	Die-cast AG-40A(2)	(L) Immersion	Room		11 days			19.7	4.3		8
(a) 11–48–0		5.4	(1)	(L) Immersion	60	140	11 days			38.5	7.7		8
(a) 11–48–0		5.4	(2)	(L) Immersion	60	140	11 days			14.2	3.1		8
(b) 16–20–0		4.1	(1)	(L) Immersion	Room		11 days			16.5	3.3		8
(b) 16–20–0		4.1	(2)	(L) Immersion	Room		11 days			14.2	3.1		8
(b) 16–20–0		4.1	(1)	(L) Immersion	60	140	11 days			83.5	16.7		8
(b) 16–20–0		4.1	(2)	(L) Immersion	60	140	11 days			77.5	16.9		8
(c) 33.5–0–0		3.5	(1)	(L) Immersion	Room		11 days			250.0	50.0		8
(b) 33.5–0–0		3.5	(2)	(L) Immersion	Room		11 days			65.7	14.3		8
(b) 33.5–0–0		3.5	(1)	(L) Immersion	60	140	11 days			595.0	119.0		8
(b) 33.5–0–0		3.5	(2)	(L) Immersion	60	140	11 days			168.0	36.7		8
(d) 21–0–0		2.5	(1)	(L) Immersion	Room		11 days			37.0	7.4		8
(d) 21–0–0		2.5	(2)	(L) Immersion	Room		11 days			19.7	4.3		8
(d) 21–0–0		2.5	(1)	(L) Immersion	60	140	11 days			84.5	16.9		8
(d) 21–0–0		2.5	(2)	(L) Immersion	60	140	11 days			47.3	10.3		8
(e) 27–14–0	(a), (b)	4.5	(1)	(L) Immersion	Room		11 days			92.0	18.4		8
(e) 27–14–0	(a), (b)	4.5	(2)	(L) Immersion	Room		11 days			29.8	6.5		8
(e) 27–14–0	(a), (b)	4.5	(1)	(L) Immersion	60	140	11 days			345.0	69.0		8
(e) 27–14–0	(a), (b)	4.5	(2)	(L) Immersion	60	140	11 days			60.5	13.2		8
(f) 8–32–16	(a), (d), KCl	5.0	(1)	(L) Immersion	Room		11 days			92.0	18.4		8
(f) 8–32–16	(a), (d), KCl	5.0	(2)	(L) Immersion	Room		11 days			32.5	7.1		8
(f) 8–32–16	(a), (d), KCl	5.0	(1)	(L) Immersion	60	140	11 days			130.0	26.0		8
(f) 8–32–16	(a), (d), KCl	5.0	(2)	(L) Immersion	60	140	11 days			100.0	22.0		8
(g) 6–24–24	(a), (d), KCl	5.2	(1)	(L) Immersion	Room		11 days			93.0	18.6	Heterogeneous mixture	8
(g) 6–24–24	(a), (d), KCl	5.2	(2)	(L) Immersion	Room		11 days			44.9	9.8	Heterogeneous mixture	8
(g) 6–24–24	(a), (d), KCl	5.2	(1)	(L) Immersion	60	140	11 days			135.0	27.0	Heterogeneous mixture	8
(g) 6–24–24	(a), (d), KCl	5.2	(2)	(L) Immersion	60	140	11 days			67.5	14.7	Heterogeneous mixture	8
Liquid fertilizers													
27–14–0.25% solution			99.99% Zn	(L) Partial immersion	Room		21 days	None	None	34.0	6.8		8
27–14–0.25% solution			99.99% Zn	(L) Partial immersion	Room		14 days	Oxygen added daily	...	114.5	22.9		8
27–14–0.25% solution			99.99% Zn	(L) Partial immersion	60	140	21 days	None	None	44.5	8.9		8

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm^2/day(b)	mil/year	Remarks	Ref
27–14–0.25% solution	99.99% Zn	(L) Partial immersion	60	140	14 days	Oxygen added daily	. . .	105.0	21.0		8
27–14–0.25% solution	99.99% Zn	(L) Total immersion	Room		21 days	None	None	6.5	1.3		8
27–14–0.25% solution	99.99% Zn	(L) Total immersion	Room		14 days	Oxygen added daily	. . .	33.5	6.7		8
27–14–0.25% solution	99.99% Zn	(L) Total immersion	60	140	21 days	None	None	8.5	1.7		8
27–14–0.25% solution	99.99% Zn	(L) Total immersion	60	140	14 days	Oxygen added daily	. . .	45.0	9.0		8
6–16–7 liquid fertilizer	99.99% Zn	(L) Immersion	Room		16 days	. . .	. . .	23.5	4.7		8
6–16–7 liquid fertilizer	99.99% Zn	(L) Immersion	60	140	8 days	. . .	. . .	75.5	15.1		8
6–16–7 liquid fertilizer	99.99% Zn	(L) Partial immersion	Room		16 days	. . .	. . .	40.5	8.1		8
6–16–7 liquid fertilizer	99.99% Zn	(L) Partial immersion	60	140	8 days	. . .	. . .	8.5	1.7		8
6–16–7 liqiud fertilizer	99.99% Zn	(L) Alternate immersion	Room		14 days	None	. . .	18.5	3.7		8
EB-32 fertilizer solution, contains elemental S, and 0.1% $Na_2Cr_2O_7$	99.99+% Zn	(L) Immersion	60	140	. . .	None	None	46 500.0	9 300.0		8
8–24–0 fertilizer solution	99.99+% Zn	(L) Immersion	Room		5 h	None	None	515.0	103.0		8
8–24–0 fertilizer solution	99.99+% Zn	(L) Immersion	Room		10 h	None	None	400.0	80.0		8
8–24–0 fertilizer solution	99.99+% Zn	(L) Immersion	Room		100 h	None	None	240.0	48.0		8
Herbicides											
7% zinc sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	6.5	1.3		8
7% zinc sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	6.5	1.3		8
40% zinc sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	3.0	0.6		8
40% zinc sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	6.5	1.3		8
7% ammonium sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	35.0	7.0		8
7% ammonium sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	65.0	13.0		8
40% ammonium sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	45.0	9.0		8
40% ammonium sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	75.0	15.0		8
7% guanidine sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	28.0	5.6		8
7% guanidine sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	24.0	4.8		8
40% guanidine sulfamate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	4.5	0.9		8
40% guanidine sulfamate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	4.5	0.9		8
7% Du Pont Ammate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	11.0	2.2		8
7% Du Pont Ammate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	41.5	8.3		8
40% Du Pont Ammate	Comm. zinc	(L) Immersion	Room		28 days	. . .	. . .	3.5	0.7		8
40% Du Pont Ammate	Galv. steel	(L) Immersion	Room		28 days	. . .	. . .	61.5	12.3		8
Urea											
20% solution	99.99% Zn	(L) Immersion	30	86	1 month	. . .	. . .	. . .	Trace	Solutions changed weekly	8
Saturated urea solution	99.99% Zn	(L) Immersion	30	86	1 month	. . .	. . .	1.0	0.2	Solutions changed weekly	8
Moist urea salts–3% water	99.99% Zn	(L) Immersion	30	86	1 month	. . .	. . .	10.1	2.1	Slight pitting, kept moist daily	8
Aluminum chloride											
26% $AlCl_3 \cdot 6H_2O$ solution	. . .	(F) Immersion	10	50	21 days	None	None	13 970.0	2 800.0		1
Ammonia (liquid anhydrous)											
Technical grade	Zinc (99.8% pure)	(L) In vapor	Room		1 month	. . .	. . .	1.6	0.3		9
					8 months	. . .	. . .	0.09	0.2		9
Ammonium chloride											
0.1 *N* solution	HG zinc	(L) Immersion	35	95	2 days	. . .	None	38.3	7.7		1
10% solution	Cp zinc	(L) Immersion	20	68	. . .	. . .	. . .	19.0	3.8		10
10% solution	Zn-1Pb	(L) Immersion	20	68	. . .	. . .	. . .	17.0	3.4		10
10% solution	Zn-1Cd	(L) Immersion	20	68	. . .	. . .	. . .	38.0	7.6		10
10% solution	98.5% Zn	(L) Immersion	20	68	. . .	. . .	. . .	30.0	6.0		10
Ammonium hydroxide											
Reagent		(L) Immersion	30	86	2 days	None	. . .	46.1	9.3		1
Reagent		(L) Immersion	30	86	2 days	Yes	. . .	75.5	15.0		1
Ammonium hydroxide											
1.8% solution	Galv. steel	(L) In vapor	Room		30 days	. . .	. . .	6.2(g) 0.4(h) 0.1(d) 0.1(e)	1.3 0.08 0.02 0.02		4

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm^2. (d) Chromium in surface film, 1.3 μg/dm^2. (e) Chromium in surface film, 2.2 μg/dm^2. (f) Chromium in surface film, 0.1 μg/dm^2. (g) Chromium in surface film, 0 μg/dm^2. (h) Chromium in surface film, 0.2 μg/dm^2

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
3.5% solution (1*N*)	Comm. zinc	(L) Immersion	30	86	2 days	None	None	58.0	11.6		4
3.5% solution (1*N*)	Comm. zinc	(L) Immersion	30	86	2 days	15–20 air bubbles per min	· · ·	141.0	28.2		4
Ammonium acid fluoride											
5% $NH_4F \cdot HF$ solution	99.9% Zn	(L) Immersion	20	68	1 day	· · ·	· · ·	189.0	38.0	Corrosion products not removed	10
10% $NH_4F \cdot HF$ solution	99.9% Zn	(L) Immersoin	20	68	1 day	· · ·	· · ·	381.0	76.0	Corrosion products not removed	10
20% $NH_4F \cdot HF$ solution	99.9% Zn	(L) Immersion	20	68	14 days	· · ·	· · ·	420.0	84.0	Corrosion products not removed	10
Ammonium sulfate											
10% solution + free ammonia	Galv.	(L) Immersion	· · ·	· · ·	· · ·	· · ·	· · ·	61.0	12.2		1
Building materials											
Gypsum plaster (0.046% chloride)	Rolled sheet	(L) Partly embedded	Room		82 days	· · ·	· · ·	· · ·	30.0	Perforated, kept damp	11
Gypsum plaster (0.046% chloride)	Rolled sheet	(L) Partly embedded	Room		107 days	· · ·	· · ·	3.0	0.6	Dried	11
Gypsum plaster (0.046% chloride)	Rolled sheet	(L) Partly embedded	Room		203 days	· · ·	· · ·	2.1	0.4	Dried	11
Gypsum plaster (0.046% chloride)	Rolled sheet + Cronak	(L) Partly embedded	Room		107 days	· · ·	· · ·	0.3	<0.1	Kept damp	11
Gypsum plaster (0.046% chloride)	Rolled sheet + Cronak	(L) Partly embedded	Room		203 days	· · ·	· · ·	0.3	<0.1	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Partly embedded	Room		91 days	· · ·	· · ·	200.0	· · ·	Pitting at air interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Partly embedded	Room		6 months	· · ·	· · ·	30.7	· · ·	Pitting at air interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Partly embedded	Room		12 months	· · ·	· · ·	37.1	· · ·	Pitting at air interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Partly embedded	Room		91 days	· · ·	· · ·	0.0	· · ·	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Partly embedded	Room		6 months	· · ·	· · ·	0.8	0.2	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Partly embedded	Room		12 months	· · ·	· · ·	0.2	<0.1	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Partly embedded	Room		91 days	· · ·	· · ·	88.7	· · ·	Corrosion at interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Partly embedded	Room		6 months	· · ·	· · ·	44.5	· · ·	Corrosion at interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Partly embedded	Room		12 months	· · ·	· · ·	29.4	· · ·	Corrosion at interface, kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Surface contact	Room		91 days	· · ·	· · ·	115.0	25.0	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Surface contact	Room		6 months	· · ·	· · ·	101.7	22.0	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A)	(L) Surface contact	Room		12 months	· · ·	· · ·	83.8	18.0	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Surface contact	Room		91 days	· · ·	· · ·	0.4	<0.1	Kept damp	11
Building materials											
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Surface contact	Room		6 months	· · ·	· · ·	1.33	0.3	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + Cronak	(L) Surface contact	Room		12 months	· · ·	· · ·	0.98	0.2	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Surface contact	Room		91 days	· · ·	· · ·	154.5	34.0	Kept damp	11

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Surface contact	Room		6 months	...	...	114.2	25.0	Kept damp	11
Gypsum plaster + 1.5% sodium chloride	Die casting (BS1004 Alloy A) + phosphate	(L) Surface contact	Room		12 months	...	...	84.1	18.0	Kept damp	11
Plaster of paris	Rolled sheet	Specimen partly embedded and immersed in H_2O	Room		32 days	...	...	1.5	0.3	H_2O content of plaster during test, 28%	12
Plaster of paris	Rolled sheet	Specimen partly embedded and immersed in H_2O	Room		71 days	...	...	1.3	0.3	H_2O content of plaster during test, 28%	12
Plaster of paris	Electrolytic	Specimen partly embedded and immersed in H_2O	Room		32 days	...	...	1.4	0.3	H_2O content of plaster during test, 28%	12
Plaster of paris	Electrolytic	Specimen partly embedded and immersed in H_2O	Room		71 days	...	...	2.1	0.4	H_2O content of plaster during test, 28%	12
Plaster of paris	Rolled sheet	Specimen partly embedded, in desiccator over H_2O	Room		32 days	...	...	23.7	4.7	Localized pitting, H_2O content of plaster during test, 15%	12
Plaster of paris	Rolled sheet	Specimen partly embedded, in desiccator over H_2O	Room		71 days	...	...	18.3	3.7	Localized pitting, H_2O content of plaster during test, 15%	12
Plaster of paris	Electrolytic	Specimen partly embedded, in desiccator over H_2O	Room		32 days	...	...	23.4	4.7	Localized pitting, H_2O content of plaster during test, 15%	12
Plaster of paris	Electrolytic	Specimen partly embedded, in desiccator over H_2O	Room		71 days	...	...	22.4	4.5	Localized pitting, H_2O content of plaster during test, 15%	12
Plaster of paris	Rolled sheet	Specimen partly embedded	Room		32 days	...	...	25.3	5.1	Uniform attack, kept damp	12
Plaster of paris	Rolled sheet	Specimen partly embedded	Room		71 days	...	...	43.4	8.7	Uniform attack, kept damp	12
Plaster of paris	Electrolytic	Specimen partly embedded	Room		32 days	...	...	29.4	5.9	Uniform attack, kept damp	12
Plaster of paris	Electrolytic	Specimen partly embedded	Room		71 days	...	...	39.9	8.0	Uniform attack, kept damp	12
Cement	Rolled sheet	Specimen partly embedded, immersed in H_2O	Room		34 days	...	...	1.68	0.3		12
Cement	Rolled sheet	Specimen partly embedded, immersed in H_2O	Room		62 days	...	...	1.03	0.2		12
Cement	Electrolytic	Specimen partly embedded, immersed in H_2O	Room		34 days	...	...	2.0	0.4		12
Cement	Electrolytic	Specimen partly embedded, immersed in H_2O	Room		62 days	...	...	1.13	0.2		12
Cement	Rolled sheet	Specimen partly embedded, in desiccator over water	Room		34 days	...	...	1.85	0.4		12
Cement	Rolled sheet	Specimen partly embedded, in desiccator over water	Room		62 days	...	...	1.37	0.3		12
Cement	Electrolytic	Specimen partly embedded, in desiccator over water	Room		34 days	...	...	2.12	0.4		12
Cement	Electrolytic	Specimen partly embedded, in desiccator over water	Room		62 days	...	...	1.53	0.3		12
Wood from linden tree	Rolled sheet	In contact under H_2O	Room		61 days	...	...	4.88	1.0		12
Wood from linden tree	Electrolytic	In contact under H_2O	Room		61 days	...	...	3.90	0.8		12
Wood from pine tree	Rolled sheet	In contact under H_2O	Room		61 days	...	...	2.74	0.5		12
Wood from pine tree	Electrolytic	In contact under H_2O	Room		61 days	...	...	3.94	0.8		12

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
Wood from beech tree	Rolled sheet	In contact under H_2O	Room		61 days	...	...	2.51	0.5		12
Wood from beech tree	Electrolytic	In contact under H_2O	Room		61 days	...	...	2.30	0.5		12
Sulfur-containing clay	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.1	<0.1		10
Quartz sand	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.1	<0.1		10
Fibrolite	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.03	<0.1		10
Asbestos cement	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.03	<0.1		10
White granulated slag	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.3	<0.1		10
Red brick	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.4	<0.1		10
Mineral wood	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.5	0.1		10
Asbestos	Electrogalv. sheet	Contact	19	66	30 days	...	...	0.8	0.16		10
Portland cement/sand mortar	Electrogalv. sheet	Contact	19	66	30 days	...	...	2.1	0.4		10
Gypsum plaster	Electrogalv. sheet	Contact	19	66	30 days	...	...	2.6	0.5		10
Silica brick	Electrogalv. sheet	Contact	19	66	30 days	...	...	7.4	1.5		10
Calcium chlorate											
1.57% ClO_3	Sheet	(L) Immersion	...		10 days	...	...	14.0	2.8		1
Calcium chloride											
1.1% solution	HG zinc	(L) Partial immersion	35	95	2 days	...	None	32.3	6.5		1
20% solution	Sheet	(L) Partial immersion	−5	23	30 days	...	Yes	12.0	2.4	Based on immersed area	1
20% solution	Galv. sheet	(L) Partial immersion	−5	23	30 days	...	Yes	>15.4	>2.8	Based on immersed area	1
20% solution	Sheet	(L) Partial immersion	33	91	10 days	None	None	3.45	0.7		1
20% solution	Galv. sheet	(L) Partial immersion	33	91	10 days	None	None	2.26	0.5		1
20% solution silicate	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.52	0.5		1
20% solution + 0.05% $Ca(OH)_2$	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.61	0.5		1
20% solution + 0.17% $Na_2Cr_2O_7$	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.20	0.4		1
Citric acid											
2% solution	Sheet	(L) Immersion	Room		21 days	None	None	...	...	Specimen dissolved	1
m-Cresol											
Pure, dry	Sheet	(L) Contact	25	77	100 days	None	None	0.15	<0.1		1
Pure, dry	Sheet	(L) In vapors			100 days	...	...	Very high	...		1
Pure + 10% water	Sheet	(L) Contact	25	77	100 days	None	None	0.26	<0.1		1
Pure + 10% water	Sheet	(L) In vapors			100 days	...	...	282.0	56.0		1
o-Cresol											
Pure, dry	Sheet	(L) Contact	25	77	100 days	None	None	0.26	<0.1		1
Pure, dry	Sheet	(L) In vapors			100 days	...	...	271.0	54.0		1
Pure + 10% water	Sheet	(L) Contact	25	77	100 days	None	None	0.07	<0.1		1
Pure + 10% water	Sheet	(L) In vapors			100 days	...	...	56.2	11.2		1
Detergents and cleaners											
Calcium chloride 20% solution	Sheet	(L) Partial immersion	33	91	10 days	None	None	3.45	0.7	Dairy cleaning	1
Calcium chloride 20% solution	Galv. sheet	(L) Partial immersion	33	91	10 days	None	None	2.26	0.5	Dairy cleaning	1
Calcium chloride 20% solution + silicate	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.52	0.5	Dairy cleaning	1
Calcium chloride 20% solution + 0.05% $Ca(OH)_2$	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.61	0.5	Dairy cleaning	1
Calcium chloride 20% solution + 0.17% $Na_2Cr_2O_7$	Sheet	(L) Partial immersion	35	95	10 days	None	None	2.20	0.4	Dairy cleaning	1
Lime mix: 2 lb/gal of 66.5% calcium hydroxide + 32.5% magnesium oxide	Sheet	(L) Partial immersion	21	70	5 days	None	None	7.34	1.5	Dairy cleaning	1
Sodium carbonate	Sheet	(L) Partial immersion	66	150	5 h	None	None	39.0	7.8	Dairy cleaning	1
Sodium carbonate	Galv. sheet	(L) Partial immersion	66	150	5 h	None	None	37.0	7.4	Dairy cleaning	1
Sodium hydroxide, 0.5% solution	Sheet	(L) Partial immersion	66	150	5 h	None	None	89.0	17.8	Dairy cleaning	1
Sodium hydroxide, 0.5% solution	Sheet	(L) Partial immersion	21	70	5 days	None	None	4.7	0.9	Dairy cleaning	1
Sodium hydroxide, 0.5% solution	Galv. sheet	(L) Partial immersion	66	150	5 h	None	None	204.0	41.0	Dairy cleaning	1
Sodium hydroxide, 0.5% solution	Galv. sheet	(L) Partial immersion	21	70	5 days	None	None	12.0	2.4	Dairy cleaning	1

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
Sodium hypochlorite, 1 oz/gal, 236 ppm available chlorine	Sheet	(L) Partial immersion	21	70	5 days	None	None	21.6	4.3	Dairy cleaning	1
Sodium hypochlorite, 1 oz/gal, 236 ppm available chlorine	Galv. sheet	(L) Partial immersion	21	70	5 days	None	None	20.6 g/m^2	4.1	Dairy cleaning	1
Diversol, 1.1 oz/gal, 236 ppm available chlorine	Sheet	(L) Partial immersion	21	70	5 days	None	None	4.8 g/m^2	1.0	Dairy cleaning	1
Diversol, 1.1 oz/gal, 236 ppm available chlorine	Galv. sheet	(L) Partial immersion	21	70	5 days	None	None	Gained weight	···	Dairy cleaning	1
Diversol, 0.64 oz/gal, 137 ppm available chlorine	Sheet	(L) Partial immersion	21	70	5 days	None	None	5.9 g/m^2	1.2	Dairy cleaning	1
Diversol, 0.64 oz/gal, 137 ppm available chlorine	Galv. sheet	(L) Partial immersion	21	70	5 days	None	None	7.3 g/m^2	1.5	Dairy cleaning	1
Chloramine T, 0.1 oz/gal, 222 ppm available chlorine	Sheet	(L) Partial immersion	21	70	5 days	None	None	16.9 g/m^2	3.4	Dairy cleaning	1
Chloramine T, 0.1 oz/gal, 222 ppm available chlorine	Galv. sheet	(L) Partial immersion	21	70	5 days	None	None	0	0	Dairy cleaning	1
Trisodium phosphate											
0.16% solution	Sheet	(L) Partial immersion	66	150	5 h	None	None	29.0 g/m^2	5.8	Dairy cleaning	1
0.16% solution	Galv. sheet	(L) Partial immersion	66	150	5 h	None	None	1.3 g/m^2	0.3	Dairy cleaning	1
0.50% solution	Sheet	(L) Partial immersion	66	150	5 h	None	None	24.0 g/m^2	4.8	Dairy cleaning	1
0.50% solution	Galv. sheet	(L) Partial immersion	66	150	5 h	None	None	Gained weight	···	Dairy cleaning	1
Carbon tetrachloride-benzol, 90%–10% mixture	Sheet	(F) Immersion	Room		40 days	None	None	41.7 g/m^2	>4.0	Dry cleaning	1
Carbon tetrachloride-benzol, 90%–10% mixture	Sheet	(F) Immersion	40	287	38 days	None	Boiling			Dry cleaning; specimen destroyed	1
Perchlorethylene	Sheet	(F) In vapor	27	260	64 days	None	None	117.8 g/m^2	23.0	Dry cleaning	1
Perchlorethylene	Sheet	(F) Immersion	51	305	64 days	None	Boiling	407.5 g/m^2	82.0	Dry cleaning	1
Sodium tripolyphosphate, 0.08%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	5.50 g/m^2	38.0	Individual component of Syndet at concentration present in detergent	13
Tetrasodium pyrophosphate, 0.085%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	3.88 g/m^2	26.8	As above	13
Sodium perborate, 0.064%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.78 g/m^2	5.4	Individual components of Syndet at concentration present in detergent	13
Sodium carbonate, 0.18%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.50 g/m^2	3.4	As above	13
Sodium sulfate, 0.12%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.20 g/m^2	1.4	As above	13
Sodium chloride, 0.004%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.39 g/m^2	2.7	As above	13
Sodium metasilicate, 0.045%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.52 g/m^2	3.6	As above	13
Lauryl alcohol sulfonate, 0.18%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.43 g/m^2	3.0	As above	13
Lauric acid ethanolamide, 0.015%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	0.15 g/m^2	1.0	As above	13
Sodium tripolyphosphate, 0.15%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	49.8 g/m^2	201.0	Solution also contained 0.1% sodium perborate; solution renewed every hour	14
Sodium tripolyphosphate, 0.50%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	68.0 g/m^2	274.0	As above	14
Tetrasodium pyrophosphate, 0.15%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	44.1 g/m^2	177.0	As above	14
Sodium metaphosphate, 0.15%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	48.7 g/m^2	196.0	As above	14
Ordinary soap, 0.3%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	6.4 g/m^2	26.0	As above	14
Lauryl sulfate, 0.05%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	Gain	···	As above	14
Sodium carbonate, tech. calcined, 0.1%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	3.3 g/m^2	13.0	As above	14
Sodium metasilicate · $5H_2O$, 0.03%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	0.6 g/m^2	2.4	As above	14
Sodium sulfate, cryst., 0.05%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	6.6 g/m^2	27.0	As above	14

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Sodium tripolyphosphate, 0.15%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	11.3 g/m^2	45.5	Perborate-free solutions	14
Sodium carbonate, 0.1%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	1.4 g/m^2	5.6	Perborate-free solutions	14
Sodium metasilicate $5H_2O$, 0.03%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	Gain	...	Perborate-free solutions	14
Ordinary soap, 0.03%	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	6.5 g/m^2	26.0	Perborate-free solutions	14
Tetrasodium pyrophosphate											
0.01%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	0.15 g/m^2	22.0	Effect of solution concentration and duration of immersion	13
0.05–2.5%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	1.03 g/m^2	148.0	As above	13
0.1%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	1.03 g/m^2	148.0	As above	13
0.1%	Hot dip galv.	(L) Immersion	95	203	80 min	None	None	1.65 g/m^2	60.0	As above	13
0.1%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	3.88 g/m^2	27.0	As above	13
Sodium tripolyphosphate											
0.01%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	0.10 g/m^2	15.0	Effect of solution concentration and duration of immersion	13
0.05–1%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	1.19 g/m^2	173.0	As above	13
0.08%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	1.19 g/m^2	73.0	As above	13
0.08%	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	2.18 g/m^2	79.0	As above	13
0.08%	Hot dip galv.	(L) Immersion	95	203	7 h	None	None	5.50 g/m^2	38.0	As above	13
Tetrasodium pyrophosphate											
0.5 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle	From boiling	From boiling	6.0 g/m^2/5 cycles	77.4	g/m^2/5 cycles × 12.9 = mil/year	15
0.5 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	1.2 g/m^2/5 cycles	15.4		15
0.5 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	1.5 g/m^2/5 cycles	19.4		15
1.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	11.2 g/m^2/5 cycles	144.3		15
1.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	4.7 g/m^2/5 cycles	60.7		15
1.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	5.1 g/m^2/5 cycles	65.7		15
2.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	25.8 g/m^2/5 cycles	333.0		15
2.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	19.0 g/m^2/5 cycles	254.0		15
2.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	21.2 g/m^2/5 cycles	273.0		15
3.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	34.5 g/m^2/5 cycles	445.0		15
3.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	27.2 g/m^2/5 cycles	351.0		15
3.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	32.8 g/m^2/5 cycles	423.0		15
Sodium tripolyphosphate											
0.5 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle	From boiling	From boiling	5.4 g/m^2/5 cycles	69.7		15
0.5 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	2.8 g/m^2/5 cycles	36.1		15
0.5 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	3.7 g/m^2/5 cycles	47.7		15
1.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	14.8 g/m^2/5 cycles	191.0		15
1.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	8.5 g/m^2/5 cycles	110.0		15
1.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	11.4 g/m^2/5 cycles	147.0		15
2.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	36.9 g/m^2/5 cycles	476.0		15
2.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	24.9 g/m^2/5 cycles	321.0		15
2.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	29.7 g/m^2/5 cycles	383.0		15
3.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	46.2 g/m^2/5 cycles	596.0		15
Sodium tripolyphosphate											
3.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	32.6 g/m^2/5 cycles	421.0		15
3.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	39.8 g/m^2/5 cycles	513.0		15
Sodium metaphosphate											
0.5 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle	From boiling	From boiling	5.9 g/m^2/5 cycles	76.1		15

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
0.5 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	3.7 g/m²/5 cycles	47.7		15
0.5 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	4.8 g/m²/5 cycles	61.9		15
1.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	17.1 g/m²/5 cycles	221.0		15
1.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	9.9 g/m²/5 cycles	128.0		15
1.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	15.9 g/m²/5 cycles	205.0		15
2.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	32.9 g/m²/5 cycles	424.0		15
2.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	28.1 g/m²/5 cycles	362.0		15
2.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	33.1 g/m²/5 cycles	427.0		15
3.0 g/L in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	49.0 g/m²/5 cycles	632.0		15
3.0 g/L in 21 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	37.4 g/m²/5 cycles	482.0		15
3.0 g/L in 21 gr water + 1 g/L perborate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	47.4 g/m²/5 cycles	612.0		15
Tetrasodium pyrophosphate											
0.06% solution	Sheet	(L) Immersion	80	176	6 h	None	None	0.63 mg/in.²/h	47.0		16
0.15% solution of mixture: 40% tetrasodium pyrophosphate + 30% trisodium phosphate 12 H_2O + 30% sodium metasilicate · $5H_2O$	Sheet	(L) Immersion	80	176	6 h	None	None	0.48 mg/in.²/h	36.0		16
0.15% solution of mixture: 31.2% sodium hexametaphosphate + 24.7% trisodium phosphate 12 H_2O + 39.2% sodium metasilicate $5H_2O$ + 4.5% sodium carbonate	Sheet	(L) Immersion	80	176	6 h	None	None	0.15 mg/in.²/h	11.0		16
Commercial soaps and Syndets											
Syndet (1)–0.2% solution (Fab)	Sheet	(L) Immersion	Room		1 week	None	None	6.45 mg/in.²/h	1.3		1
Syndet (1)–0.2% solution (Fab)	Sheet	(L) Immersion	60	140	7 h	None	None	0.7 mg/in.²/h	<0.1		1
Syndet (2)–0.2% solution (Mytron)	Sheet	(L) Immersion	Room		1 week	None	None	24.2 mg/in.²/h	4.9		1
Syndet (2)–0.2% solution (Mytron)	Sheet	(L) Immersion	60	140	7 h	None	None	1.63 mg/in.²/h	0.3		1
Syndet (2)–0.2% solution + sodium silicate	Sheet	(L) Immersion	Room		1 week	None	None	33.5 mg/in.²/h	6.7		1
Syndet (3)–0.2% solution (OS)	Sheet	(L) Immersion	Room		1 week	None	None	24.0 mg/in.²/h	4.8		1
Syndet (4)–0.2% solution (Tide)	Sheet	(L) Immersion	Room		1 week	None	None	11.1 mg/in.²/h	2.2		1
Syndet (4)–0.02% solution (Tide)	Sheet	(L) Immersion	60	140	7 h	None	None	1.92 mg/in.²/h	0.4		1
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	1.96 g/m²	284.0		13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	80 min	None	None	2.56 g/m²	93.0	pH 10.20	13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	4 h	None	None	4.2 mg/in.²/h	51.0		13
Syndet (5) containing phosphates, 1.0% solution	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	3.4 g/m²	493.0		13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	5 consecutive 20 min on same piece	None	None	1.35 g/m²			13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	As above	None	None	1.39 g/m²			13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	As above	None	None	2.06 g/m²			13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	As above	None	None	2.10 g/m²			13
Syndet (5) containing phosphates, 0.5% solution	Hot dip galv.	(L) Immersion	95	203	As above	None	None	2.30 g/m²			13
Syndet (6)–0.4% solution	Hot dip galv.	(L) Immersion	95	203	80 min	None	None	2.08 g/m²	75.0	pH 9.89	13
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	80 min	None	None	0.65 g/m²	24.0		13
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	5 consecutive 20 min on same piece	None	None	0.20 g/m²			13

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm^2/day(b)	Corrosion rate mil/year	Remarks	Ref
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	As above	None	None	0.13 g/m^2			13
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	As above	None	None	0.07 g/m^2			13
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	As above	None	None	0.04 g/m^2			13
Soap (1)–0.8% solution pH 10.65	Hot dip galv.	(L) Immersion	95	203	As above	None	None	0.02 g/m^2			13
Soap (2)–0.08% solution pH 10.73	Hot dip galv.	(L) Immersion	95	203	80 min	None	None	0.22 g/m^2	8.0		13
Soap (2)–0.08% solution pH 10.73	Hot dip galv.	(L) Immersion	95	203	4 h	None	None	0.22 g/m^2	2.7		13
Soap (2)–0.5% solution	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	0.17 g/m^2	25.0		13
Soap (2)–2.0% solution	Hot dip galv.	(L) Immersion	95	203	20 min	None	None	0.24 g/m^2	35.0		13
Syndet (7) (USA) in 0 gr water	Sheet	(L) Immersion	Boiling		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle	From boiling	From boiling	49.0 g/m^2/5 cycles	632.0	g/m^2/5 cycles × 12.9 = mil/year	15
Syndet (7) (USA) in 12.5 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	24.8 g/m^2/5 cycles	320.0		15
Syndet (8) (German) in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	7.9 g/m^2/5 cycles	102.0		15
Syndet (8) (German) in 12.5 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	13.8 g/m^2/5 cycles	178.0		15
Syndet (9) (Swiss) in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	7.8 g/m^2/5 cycles	100.0		15
Syndet (9) (Swiss) in 12.5 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	14.1 g/m^2/5 cycles	182.0		15
Syndet (10) in soft water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	58.9 g/m^2/5 cycles	758.0		15
Syndet (10) + 1% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	54.2 g/m^2/5 cycles	698.0		15
Syndet (10) + 5% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	47.8 g/m^2/5 cycles	616.0		15
Syndet (10) + 10% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	31.0 g/m^2/5 cycles	400.0		15
Syndet (11) in soft water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	34.5 g/m^2/5 cycles	446.0	Contains silicates	15
Syndet (11) + 1% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	28.2 g/m^2/5 cycles	364.0		15
Syndet (11) + 5% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	17.9 g/m^2/5 cycles	231.0		15
Syndet (11) + 10% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	8.7 g/m^2/5 cycles	112.0		15
Syndet (12) in soft water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	22.4 g/m^2/5 cycles	289.0	Does not contain silicates	15
Syndet (12) + 1% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	20.4 g/m^2/5 cycles	263.0		15
Syndet (12) + 5% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	19.6 g/m^2/5 cycles	253.0		15
Syndet (12) + 10% acid orthophosphate	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	17.3 g/m^2/5 cycles	223.0		15
Hard water soap (3) (USA) in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	7.9 g/m^2/5 cycles	102.0		15
Hard water soap (3) (USA) in 12.5 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	13.2 g/m^2/5 cycles	170.0		15
Hard water soap (4) (Swiss) in 0 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	2.2 g/m^2/5 cycles	28.4		15
Hard water soap (4) (Swiss) in 12.5 gr water	Sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	6.6 g/m^2/5 cycles	85.0		15
Laboratory-prepared soap mixtures and Syndets											
L Syndet I, composition:											
Sodium tripolyphosphate, 50%											15
Sodium sulfate, 19%											15
Dodecylbenzylsulfonate, 10%											15
Sodium perborate ($4H_2O$), 8%											15

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm^2. (d) Chromium in surface film, 1.3 μg/dm^2. (e) Chromium in surface film, 2.2 μg/dm^2. (f) Chromium in surface film, 0.1 μg/dm^2. (g) Chromium in surface film, 0 μg/dm^2. (h) Chromium in surface film, 0.2 μg/dm^2

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Lauryl sulfate, 5%											15
Sodium metasilicate, 5%											15
Sodium chloride, 1%											15
Sodium salt of EDTA, 0.5%											15
Carboxymethyl cellulose, 0.5%											15
Water, 1%											15
L Syndet I, 6 g/L in 0 gr water	Zinc sheet	(L) Immersion	Boiling		5 cycles, each 30 min at boiling + 15 min cooling; solution renewed after each cycle	From boiling	From boiling	40.2 g/m²/5 cycles	518.0		15
L Syndet I, 6 g/L in 21 gr water	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	28.5 g/m²/5 cycles	368.0		15
L Syndet I, 6 g/L in 42 gr water	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	12.1 g/m²/5 cycles	156.0		15
L Syndet I, 6 g/L + 0.3 g/L sodium metasilicate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	36.4 g/m²/5 cycles	470.0		15
L Syndet I, 6 g/L +:											
0.3 g/L sodium disilicate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	32.9 g/m²/5 cycles	425.0		15
0.3 g/L sodium trisilicate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	27.6 g/m²/5 cycles	356.0		15
1.8 g/L sodium trisilicate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	18.3 g/m²/5 cycles	236.0		15
0.3 g/L monoammonium phosphate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	22.2 g/m²/5 cycles	286.0		15
0.3 g/L monoammonium phosphate, 21 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	14.6 g/m²/5 cycles	188.0		15
0.18 g/L sodium nitrate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	24.1 g/m²/5 cycles	311.0		15
0.3 g/L magnesium lactate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	19.3 g/m²/5 cycles	249.0		15
0.3 g/L magnesium lactate, 21 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	21.0 g/m²/5 cycles	271.0		15
0.3 g/L calcium chloride, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	16.0 g/m²/5 cycles	206.0		15
0.36 g/L sodium thiosulfate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	16.8 g/m²/5 cycles	217.0		15
0.3 g/L sodium aluminate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	21.7 g/m²/5 cycles	280.0		15
0.3 g/L sodium perborate, 0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	56.2 g/m²/5 cycles	725.0		15
0.3 g/L sodium perborate, 21 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	34.7g/m²/5 cycles	448.0		15
L Syndet I, 6 g/L + magnesium silicate 0.18 g/L +:											
0 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	51.9 g/m²/5 cycles	669.0		15
2 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	55.8 g/m²/5 cycles	720.0		15
4 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	64.8 g/m²/5 cycles	835.0		15
6 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	75.1 g/m²/5 cycles	968.0		15
8 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	79.0 g/m²/5 cycles	1 020.0		15
10 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	81.2 g/m²/5 cycles	1 050.0		15
12 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	82.0 g/m²/5 cycles	1 060.0		15
13 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	81.9 g/m²/5 cycles	1 060.0		15
15 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	80.4 g/m²/5 cycles	1 040.0		15
20 g/L perborate—0 gr H_2O	Zinc sheet	(L) Immersion	Boiling		As above	From boiling	From boiling	63.7 g/m²/5 cycles	821.0		15
L Syndet II, composition:											
Lauryl sulfate, 10%											14
Dodecylbenzylsulfonate, 17%											14
Sodium tripolyphosphate, 30%											14
Tetrasodium pyrophosphate, 5%											14
Waterglass (powder), 6%											14
Magnesium silicate, 2%											14
Carboxymethylcellulose, 1%											14
Sodium sulfate, 13%											14
Sodium perborate, 16%											14
L Syndet II, 6 g/L solution	Hot dip galv.	(L) Immersion	20	68	12 h	None	None	8.0 g/m²	32.0	Solutions renewed every hour	14

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
L Syndet II, 6 g/L solution	Hot dip galv.	(L) Immersion	40	104	12 h	None	None	18.0 g/m²	73.0	Solutions renewed every hour	14
L Syndet II, 6 g/L solution	Hot dip galv.	(L) Immersion	65	149	12 h	None	None	38.0 g/m²	153.0	Solutions renewed every hour	14
L Syndet II, 6 g/L solution	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	78.4 g/m²	316.0	Solutions renewed every hour	14
L Syndet II, 6 g/L solution	Hot dip galv.	(L) Immersion	90	194	12 h	Yes	Vigorous	81.4 g/m²	328.0	Solutions renewed every hour	14
L Syndet II, 6 g/L solution	Zinc sheet	(L) Immersion	90	194	12 h	None	None	67.3 g/m²	271.0	Solutions renewed every hour	14
L Syndet II, without perborate, 5 g/L	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	7.3 g/m²	29.0	Solutions renewed every hour	14
L Syndet II, without perborate, 5 g/L	Hot dip galv.	(L) Immersion	90	194	12 h	Yes	Vigorous	18.2 g/m²	73.0	Solutions renewed every hour	14
L Soap detergent I, composition:											
Ordinary soap, 40%											14
Soda, 25%											14
Trisodium phosphate, 11%											14
Tetrasodium pyrophosphate, 5%											14
Waterglass (powder), 6%											14
Magnesium silicate, 2%											14
Sodium perborate, 11%											14
L Soap detergent I, 9 g/L	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	5.1 g/m²	21.0	Solutions renewed every hour	14
L Soap detergent I, 9 g/L	Zinc sheet	(L) Immersion	90	194	12 h	None	None	1.6 g/m²	6.4	Solutions renewed every hour	14
L Soap detergent I, 8 g/L (without perborate)	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	1.9 g/m²	7.6	Solutions renewed every hour	14
L Soap detergent II for hard water, composition:											
Ordinary soap, 35%											14
Soda, 21%											14
Trisodium phosphate, 5%											14
Sodium tripolyphosphate, 20%											14
Waterglass (powder), 6%											14
Magnesium silicate, 2%											14
Sodium perborate, 11%											
L Soap Detergent II, 9 g/L	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	17.0 g/m²	68.0	Solutions renewed every hour	14
L Soap Detergent II, 9 g/L	Zinc sheet	(L) Immersion	90	194	12 h	None	None	6.1 g/m²	25.0	Solutions renewed every hour	14
L Soap Detergent II, 8 g/L (without perborate)	Hot dip galv.	(L) Immersion	90	194	12 h	None	None	7.0 g/m²	33.0	Solutions renewed every hour	14
Ethanol											
200 proof	HG zinc	(L) Immersion	Room		13 months	None	None	...	<0.1		17
200 proof, 95 v/o in distilled H_2O	HG zinc	(L) Immersion	Room		13 months	None	None	...	<0.1		17
200 proof, 75 v/o in distilled H_2O	HG zinc	(L) Immersion	Room		13 months	None	None	...	0.7		17
200 proof, 25 v/o in distilled H_2O	HG zinc	(L) Immersion	Room		13 months	None	None	...	0.7		17
190 proof, 45 v/o in tap water	HG zinc	(L) Immersion	Room		8 months	None	None	1.07	0.2		17
190 proof, 45 v/o in tap water	HG zinc	(L) Immersion	Boiling		5 days	None	Boiling	0.22	<0.1	8 h hot, 16 h cold daily	17
190 proof, 45 v/o in tap water	HG zinc	(L) In vapors	Boiling		5 days	...	...	4.38	0.9	8 h hot, 16 h cold daily	17
190 proof, 40 v/o + 5 v/o methanol in tap water	HG zinc	(L) Immersion	Room		8 months	None	None	3.87	0.8		17

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
190 proof, 40 v/o + 5 v/o methanol in tap water	HG zinc	(L) In vapors	Boiling		5 days	...	...	10.35	2.1	8 h hot, 16 h cold daily	17
190 proof, 50 v/o + 50 v/o CP glycerine	HG zinc	(L) Immersion	Room		8 months	None	None	0.84	0.2		17
190 proof + formic acid (eq to 0.10 mg KOH/g)	Sheet	(L) Partial immersion	30	86	1 week	None	None	3.3	0.7		6
190 proof + 5% water	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.0	0.0		6
Ethyl acetate											
+5 v/o water	Sheet	(L) Partial immersion	30	86	1 week	None	None	37.1	7.4		6
+ formic acid (eq to 0.10 mg KOH/g)	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.5	0.1		6
Ethylene glycol											
50 v/o	Galv. steel	(L) Immersion	−23	−10	14 days	Continuous	None	0.4	<0.1		
50 v/o	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	1.63	0.3		
50 v/o	Galv. steel	(L) Immersion	24	75	14 days	Continuous	None	3.3	0.7		
50 v/o	Galv. steel	(L) Immersion	77	170	14 days	Continuous	None	37.1	7.4		
50 v/o + 1% borax	Galv. steel	(L) Immersion	−23	−10	14 days	Continuous	None	6.67	1.3		
50 v/o + 1% borax	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	16.7	3.3		
50 v/o + 1% borax	Galv. steel	(L) Immersion	24	75	14 days	Continuous	None	7.9	1.6		
50 v/o + 1% borax	Galv. steel	(L) Immersion	77	170	14 days	Continuous	None	...	0.1		
50 v/o + 1% sodium nitrite	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	0.85	0.2		
50 v/o + 1% sodium carbonate	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	0.24	<0.1		
50 v/o + 1% sodium acetate	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	2.91	0.6		
50 v/o + 1% sodium benzoate	Galv. steel	(L) Immersion	−7	20	14 days	Continuous	None	4.05	0.8		
Formaldehyde											
0.1 g/L in air, 90% RH	Sheet	(L) In vapors	30	86	8 days	...	...	5.0	1.0		1
Formic acid											
2.5% solution	Galv. steel	(L) In vapor	Room		30 days	...	...	23[1] 6.8[2] 4.4[3] 2.3[4]	4.7 1.4 0.9 0.5		4
4.6% solution	Sheet	(L) Immersion	100	212	4 h	None	None	6 000.0	1 200.0		4
0.1 g/L in air, 90% RH	Sheet	(L) In vapors	30	86	8 days	...	...	840.0	170.0		1
Vapors in air over solution at pH 3.8, 100% RH	Sheet	(L) In vapors	Room		8 days	...	...	2.12	0.4		3
Fire-extinguishing liquids											
45 g Al $(OH)_3$, 10 g $KHCO_3$, 22 g Na_2SO_4, 113 g K_2SO_4, 10 g foaming agent per liter of solution	Zn-4Cu-0.2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	30.1	...	Weight changes determined without removing corrosion products	18
11 g Al $(OH)_3$, 8 g $KHCO_3$, 37 g Na_2SO_4, 88 g K_2SO_4, 175 g glycerin, 45 g glycol, 15 g foaming agent per liter	Zn-4Cu-0.2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	15.3	...	As above	18
187 g $KHCO_3$, 34 g $NaHCO_3$, 15 g foaming agent per liter	Zn-4Cu-O-2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	0.3	...	As above	18
47 g $NaHCO_3$, 141 g $KHCO_3$, 230 g glycerin, 63 g glycol, 15 g foaming agent per liter	Zn-4Cu-O-2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	1.3	...	As above	18
180 g NaCl + 14 g Na_2CO_3 per liter	Zn-4Cu-O-2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	8.8	...	As above	18
500 g commercial K_2CO_3 per liter	Zn-4Cu-O-2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	3.2	...	As above	18
Carbon tetrachloride (water free)	Zn-4Cu-O-2Al	(L) Partial immersion	60, days Cool, night	140, days	5 weeks	None	None	+(1.0)	...	As above	18
Carbon tetrachloride (water free)	Zn-4Cu-O-2Al	(L) In vapors	60, days Cool, night	140, days	5 weeks	None	None	+(0.9)	...	As above	18
Carbon tetrachloride + 1 v/o water	Zn-4Cu-O-2Al	(L) Immersion	60, days Cool, night	140, days	5 weeks	None	None	+(3.9)	...	As above	18
Gasoline											
100 cc untreated	HG sheet	(L) Immersion	Room		6 months	None	None	0.85	0.2		17

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
100 cc + 40 ppm Lecithin	HG sheet	(L) Immersion	Room		6 months	None	None	0.13	<0.1		17
100 cc + 40 ppm Lecithin + 10 cc water	HG sheet	(L) Immersion	Room		6 months	None	None	3.76	0.8	Corroded in water layer	17
100 cc + 10 cc water	HG sheet	(L) Immersion	Room		6 months	None	None	6.73	1.4	Pitted, corroded in water layer	17
Glue											
12.5% solution, pH 5.6	Sheet	(F) Immersion	50	120	69 days	None	Moderate	83.0	17.0		1
Glycerine											
CP 100%	HG sheet	(L) Immersion	Room		8 months	None	None	...	<0.1		17
Glycolic acid											
7.6% solution	Sheet	(L) Immersion	100	212	4 hours	...	...	36 000.0	7 200.0		1
Hydrochloric acid											
3.6% solution (IN)	Comm. zinc	(L) Immersion	30	86	2 days	None	None	7 500.0	1 510.0		5
3.6% solution (IN)	Comm. zinc	(L) Immersion	30	86	2 days	15–20 air bubbles per min	...	6 500.0	1 300.0		5
Isobutanol											
+ formic acid (eq. to 0.10 mg KOH/g)	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.4	<0.1		6
+ 5% water	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.0	0.0		6
Lithium chloride											
30% solution	Sheet	(L) Immersion	15	240	40 days	...	Boiling	Destroyed			1
30% solution	Sheet	(L) In vapors	15	240	40 days	...	...	500.0	100.0		1
Magnesium chloride · $6H_2O$											
22 °Be, 42.5% solution	Sheet	(L) Immersion	−5	23	30 days	...	Yes	8.7–15.3	1.8–3.1	Deep pits	1
1.2% solution	Electrolytic Zn	(L) Alternate immersion	20	68	7 days	...	...	28.0	5.6		10
1.2% solution	Electrolytic Zn	(L) Alternate immersion	20	68	14 days	...	...	21.0	4.2		10
Methanol											
CP	Sheet	(L) Immersion	Room		6 months	None	None	...	<0.1		19
CP	Sheet	(L)In vapors	Boiling		1 month	...	...	...	<0.1		19
100%	HG sheet	(L) Immersion	Room		8 months	None	None	0.79	0.2		17
35% solution in tap water	HG sheet	(L) Immersion	Room		8 months	None	None	2.76	0.6		17
35% solution in tap water	HG sheet	(L) In vapors	Boiling		5 days	...	...	1.08	0.2		17
30% solution in tap water	AC-41A die cast	(L) Immersion	Boiling		1 month	...	Boiling	192.0	38.4		17
30% solution in tap water	AC-41A die cast	(L) Immersion	Room		1 year	None	None	9.72	1.9		17
+ formic acid (eq. to 0.10 mg/KOH/g)	Sheet	(L) Partial immersion	30	86	1 week	None	None	8.1	1.6		6
+ 5 v/o water	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.0	0.0		6
Methyl ethyl ketone											
+ 0.03 percent acetic acid and 0.2% H_2O	Sheet	(F) Immersion	10	50	128 days	Slight	Slight	5.2	1.0		1
+ trace acetic acid and 0.1% H_2O	Sheet	(F) In vapors	10	50	30 days	...	...	1.0	0.2		1
+ heptane and trace of acetic acid and water	Sheet	(F) Immersion	24	75	142 days	Moderate	None	0.6	0.1		1
Naphtha											
Naphtha	Sheet	(F) Immersion	55	310	50 days	...	...	30.8	6.2		1
Naphtha	Sheet	(F) In vapors	55	310	50 days	...	...	9.5	1.9		1
Oil											
No. 6 fuel	Sheet	(F) Immersion	Room		267 days	None	None	0.37	<0.1		1
Crude, light	Sheet	(F) Immersion	Room		55 days	...	None	0.24	<0.1		1
Crude, light	Sheet	(F) In vapors	Room		55 days	...	...	0.29	<0.1		1
Neutral, light	Sheet	(F) In vapors	Room		55 days	...	...	1.49	0.3		1
Neutral, light	Sheet	(F) Immersion	Room		55 days	...	None	50.3	10.0		1
Perchlorethylene											
Perchlorethylene	Sheet	(F) In vapors	27	260	64 days	None	None	117.8	23.0		1
Perchlorethylene	Sheet	(F) Immersion	51	305	64 days	...	Boiling	407.5	82.0		1

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Pesticides											
Bordeaux mixture 1.3 oz gal copper sulfate + 1.3 oz/gal quicklime	AG-40A die casting	(L) Immersion	Room		20 days	None	None	0.14	<0.1	Solutions prepared from commercial products, changed after 3 and 6 days, weight changes as removed from test	17
Copper sulfate, 1.3 oz/gal	AG-40A die casting	(L) Immersion	Room		20 days	None	None	215.0	43.0	As above	17
Dry lime sulfur, 4.8 oz/gal	AG-40A die casting	(L) Immersion	Room		20 days	None	None	4.54	0.9	As above	17
Nicotine sulfate, 1/2 pint of Black Leaf 40 to 50 gal water	AG-40A die casting	(L) Immersion	Room		20 days	None	None	2.41	1.2	As above	17
White Hellebore, 0.33 oz/gal	AG-40A die casting	(L) Immersion	Room		20 days	None	None	7.20	1.4	As above	17
Calcium arsenate	AG-40A die casting	(L) Immersion	Room		20 days	None	None	Gained weight	...	As above	17
Formalin	AG-40A die casting	(L) Immersion	Room		20 days	None	None	Gained weight	...	As above	17
Paris green	AG-40A die casting	(L) Immersion	Room		20 days	None	None	Gained weight	...	As above	17
Pyrethrum	AG-40A die casting	(L) Immersion	Room		20 days	None	None	Gained weight	...	As above	17
Lead arsenate, 0.5 oz/gal	AG-40A die casting	(L) Immersion	Room		20 days	None	None	2.41	0.5		17
Chlordane-water emulsion	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	72.0	14.4		20
DDT, 5% in distilled water	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	23.0	4.6		20
Potassium fluoride											
DDT in kerosene or fuel oil	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	0.30	<0.1		20
Sodium arsenite, 8 oz/gal in distilled H_2O	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	54.0	10.8		20
Sodium chloride, 5% in distilled water	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	80.0	16.0		20
Sodium chloride, 5% in distilled water + 5% DDT	Galv. iron	(L) Partial immersion	25	77	8 weeks	None	None	41.0	8.2		20
Bordeaux mixture 1.0 oz/gal copper sulfate + 1.3 oz/gal hydrated lime	Sheet	(L) Immersion	Room		6 days	...	Yes	33.2	6.7		1
Lime sulfur, 1 part 32 °Be + 50 parts water	Sheet	(L) Immersion	Room		6 days	...	Yes	5.7	1.1		1
DDT, sulfur, Malathion emulsion	Sheet	(F)	7–32	20–90	277 days	None	Yes	6.3	1.4		1
Manzate, 70% wettable powder	Sheet	(F)	15–32	60–90	62 days	...	Yes	7.5	1.5		1
Phenol											
Pure, dry	Sheet	(L) Contact	25	77	100 days	None	None	0.13	<0.1		21
Pure, dry	Sheet	(L) In vapors	Boiling		100 days	...	...	Very high	...		21
Pure + 10% water	Sheet	(L) Contact	25	77	100 days	None	None	0.17	<0.1		21
Pure + 10% water	Sheet	(L) In vapors	Boiling		100 days	...	...	14.9	3.0		21
0.1 g/L in air, 90% RH	Sheet	(L) In vapors	30	86	8 days	...	...	1.25	0.3		21
Phenol-formalin-water mixture	Sheet	(L) Partial immersion	27	80	184 days	High	None	17.0	3.4		21
Potassium chloride											
0.01 *N* (0.07% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	40.0	8.0		22
0.01 *N* (0.07% solution)	Pure sheet	(L) Partial immersion	25	77	30 days	None	None	35.4	7.0		22
0.1 *N* (0.75% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	70.3	14.0		22
0.1 *N* (0.75% solution)	HG sheet	(L) Partial immersion	35	95	2 days	None	None	96.6	19.0		23
0.25 *N* (1.86% solution)	HG sheet	(L) Partial immersion	35	95	2 days	None	None	116.0	23.0		23
0.50 *N* (3.64% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	94.3	19.0		22
0.50 *N* (3.64% solution)	Pure sheet	(L) Partial immersion	25	77	30 days	None	None	101.6	20.0		22
1.0 *N* (7.13% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	106.3	21.0		22
2.0 *N* (13.7% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	120.0	24.0		22
2.0 *N* (13.7% solution)	Pure sheet	(L) Partial immersion	25	77	30 days	None	None	114.3	23.0		22
3.0 *N* (19.8% solution)	Pure sheet	(L) Partial immersion	25	77	4 days	None	None	144.5	29.0		22
5–15 g/L solution	98.5% Zn sheet	(L) Immersion	12	54	65 days	None	None	18.2–11.8	3.6–2.4		24
50–300 g/L solution	98.5% Zn sheet	(L) Immersion	12	54	65 days	None	None	1.1–3.4	0.2–0.7		24

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
Potassium dichromate											
14.7% solution (1*N*)	Comm. zinc	(L) Immersion	30	86	2 days	None	None	0.75	0.15		5
14.7% solution (1*N*)	Comm. zinc	(L) Immersion	30	86	2 days	15–20 air bubbles per min	...	0.40	<0.1		5
Potassium acid fluoride											
5% KF-HF solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	14.8	3.0	Corrosion products not removed	25
5% KF-HF solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	90 800.0	18 600.0	As above	25
10% KF-HF solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	22.3	4.5	As above	25
10% KF-HF solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	79 000.0	15 800.0	As above	25
20% KF-HF solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	16.5	3.3	As above	25
20% KF-HF solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	29 600.0	5 900.0	As above	25
Potassium fluoride											
5% solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	4.3	0.9	As above	25
5% solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	Gained	...	As above	25
10% solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	Gained	...	As above	25
10% solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	Gained	...	As above	25
20% solution	99.9% Zn	(L) Immersion	20	68	28 days	...	...	0.2	<0.1	As above	25
20% solution	99.9% Zn	(L) Immersion	80	176	1 day	...	...	Gained	...	As above	25
Potassium nitrate											
5 to 100 g/L solutions	98.5% Zn sheet	(L) Immersion	7	46	189 days	None	None	1.2–3.2	0.2–0.6		24
Potassium sulfate											
5 to 50 g/L solutions	98.5% Zn sheet	(L) Immersion	12	54	57 days	None	None	11.0–7.1	2.2–1.4	24	
100 g/L solution	98.5% Zn sheet	(L) Immersion	12	54	57 days	None	None	0.54	0.1		24
n-Propanol											
+ 5% water	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.3	<0.1		6
+ formic acid (eq. to 0.10 mg KOH/g)	Sheet	(L) Partial immersion	30	86	1 week	None	None	0.3	<0.1		6
Sodium bromate											
1% solution	Sheet	(L) Immersion	...	...	10 days	...	...	346.0	69.0		10
2% solution	Sheet	(L) Immersion	...	...	10 days	...	...	137.0	27.0		10
3% solution	Sheet	(L) Immersion	...	...	10 days	...	...	430.0	86.0		10
Sodium bromide											
In vapors, 30-45% RH	Sheet	(F) In vapors	24	75	365 days	Full	...	17.89	3.6		1
Sodium carbonate											
0.5% solution	Sheet	(L) Partial immersion	66	150	5 h	None	None	39.0	7.8	Rate calculated on immersed area	1
0.5% solution	Galv. iron	(L) Partial immersion	66	150	5 h	None	None	37.0	7.4		1
Sodium chlorate											
1.57% ClO_3	Sheet	(L) Immersion	...	...	10 days	...	...	13.0	2.6		10
Sodium chloride											
Solution at pH 8.5	Sheet	(F) Immersion	−8	17	90 days	...	...	126.7	25.5		1
Solution at pH 8.5	Sheet	(F) Spray	−8	17	90 days	Spray	...	66.0	13.3	Local, pitting 0.003 in. (75 μm)	1
0.5–3.0% solutions	Sheet	(L) Immersion	12	54	64 days	None	None	18.1–10.2	3.6–2.0		24
0.1 *N*, 0.58% solution	HG sheet	(L) Partial immersion	35	95	2 days	None	None	91.4	18.0		1
0.25 *N* 1.45% solution	HG sheet	(L) Partial immersion	35	95	2 days	None	None	116.3	23.0		1
0.5 *N*, 2.9% solution	Sheet	(L) Partial immersion	25	77	205 h	...	...	65.1	13.0		10
3.0% solution	Sheet	(L) Immersion	...	...	2 days	...	...	95.0	19.0		10
3.0% solution	Sheet	(L) Immersion	...	...	7 days	...	...	137.0	27.0		10
3.0% solution	Sheet	(L) Immersion	...	...	14 days	...	...	142.0	28.0		10
3.0% + 10 g/L $Na_2SO_4 \cdot 10H_2O$	Sheet	(L) Immersion	...	...	2 days	...	...	130.0	26.0		10
3.0% + 10 g/L $Na_2SO_4 \cdot 10H_2O$	Sheet	(L) Immersion	...	...	7 days	...	...	215.0	43.0		10
3.0% + 10 g/L $Na_2SO_4 \cdot 10H_2O$	Sheet	(L) Immersion	...	...	14 days	...	...	225.0	45.0		10
3.0% + 12 g/L $MgCl_2 \cdot 6H_2O$	Sheet	(L) Immersion	...	...	2 days	...	...	5.0	1.0		10
3.0% + 12 g/L $MgCl_2 \cdot 6H_2O$	Sheet	(L) Immersion	...	...	7 days	...	...	3.0	0.6		10
3.0% + 12 g/L $MgCl_2 \cdot 6H_2O$	Sheet	(L) Immersion	...	...	14 days	...	...	3.0	0.6		10
3.5%, pH 7.0	Sheet	(L) Immersion	30	86	21 days	Saturated	16 ft/min	75.0	15.0	Maximum 0.007 in. pits (175 μm)	1

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	°F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	mil/year	Remarks	Ref
3.5% pH 7.0	Sheet	(L) Immersion	30	86	42 days	Saturated	16 ft/min	64.0	12.8	Maximum 0.016 in. pits (402 μm)	1
3.5%, pH 7.0	Galv., 0.001 in. Zn	(L) Immersion	30	86	21 days	Saturated	16 ft/min	37.0	7.4		1
3.5%, pH 7.0	Galv., 0.0015 in. Zn	(L) Immersion	30	86	21 days	Saturated	16 ft/min	74.0	14.8	0.001–0.003 in. pits (25–75 μm)	1
3.5%, pH 7.0	Galv., 0.003 in. Zn	(L) Immersion	30	86	21 days	Saturated	16 ft/min	111.0	22.2	0.001 to 0.003 in. pits (25–75 μm)	1
3.5%, pH 7.0	Galv., 0.001 in. Zn	(L) Immersion	30	86	42 days	Saturated	16 ft/min	19.0	3.8		1
3.5%, pH 7.0	Galv., 0.0015 in. Zn	(L) Immersion	30	86	42 days	Saturated	16 ft/min	23.0	4.6		1
3.5%, pH 7.0	Galv., 0.003 in. Zn	(L) Immersion	30	86	42 days	Saturated	16 ft/min	45.0	9.2		1
1 *N*, 5.6%, pH 7.85	Sheet	(L) Immersion	35	95	31 days	300 cc/min	15 ft/s	9.3	1.9		26
1 *N*, 5.6%, pH 8.00	Sheet	(L) Immersion	35	95	30 days	300 cc/min	15 ft/s	37.0	7.4	<0.001 in. pits (<25 μm)	1
1 *N*, 5.6%	Sheet	(L) Immersion	30	86	2 days	15–20 air bubbles per min	None	65.5	13.1		5
1 *N*, 5.6%	Sheet	(L) Immersion	30	86	2 days	None	None	25.0	5.0		5
20.0% solution	Sheet	(L) Immersion	Room		500 h	None	None	1.62	0.3		1
20.0% solution	Sheet	(L) Spray	35	95	21 days	...	...	72.0	14.4		1
20.0% solution	Sheet	(L) Spray	35	95	63 days	...	...	32.0	6.4		1
20.0% solution	Sheet	(L) Spray	35	95	119 days	...	...	81.0	16.2		1
20.0% solution	Galv. steel	(L) Spray	35	95	21 days	...	...	74.0	14.8	0.004 in. pits (<100 μm)	1
20.0% solution	Galv. steel	(L) Spray	35	95	63 days	...	...	20.0	4.0	0.006 in. pits (150 μm)	1
20.0% solution	Galv. steel	(L) Spray	35	95	119 days	...	...	22.0	4.4	0.019 in. pits (480 μm)	1
22 °Be, 24% solution	Sheet	(L) Partial immersion	−5	23	30 days	...	Yes	2.0–8.7	0.4–1.8	Deep pits, rate calculated on immersed area	1
60–400 g/L solutions	98.5% Zn	(L) Immersion	12	54	64 days	None	None	7.5–2.5	1.5–0.5		24
Sodium hydroxide											
0.5% solution	Sheet	(L) Partial immersion	21	70	5 days	None	None	4.7	0.9	Based on immersed area	1
0.5% solution	Galv. iron	(L) Partial immersion	21	70	5 days	None	None	12.0	2.4	Based on immersed area	1
0.5% solution	Sheet	(L) Partial immersion	66	150	5 h	None	None	89.0	17.8	Based on immersed area	1
0.5% solution	Galv. iron	(L) Partial immersion	66	150	5 h	None	None	204.0	40.8	Based on immersed area	1
3.9% solution (1 *N*)	Comm. zinc	(L) Immersion	30	86	2 days	None	None	87.5	17.5		5
3.9% solution (1 *N*)	Comm. zinc	(L) Immersion	30	86	2 days	15–20 air bubbles per min	...	175.0	35.0		5
50% solution	Sheet	(L) Immersion	30	86	1 day	None	None	5 940.0	1 190.0		5
50% solution	Sheet	(L) Immersion	30	86	1 day	None	None	4 280.0	860.0		5
50% solution	Galv. iron	(L) Immersion	30	86	1 day	None	None	379.0	75.0		5
Sodium sulfate											
5 to 300 g/L $Na_2SO_4 \cdot 10H_2O$	98.5% Zn	(L) Immersion	12	54	60 days	None	None	13 to 2	2.6–0.4		24
10 g/L $Na_2SO_4 \cdot 10H_2O$	Electrolytic zinc	(L) Immersion	...	...	2 days	...	...	10.0	2.0		10
10 g/L $Na_2SO_4 \cdot 10H_2O$	Electrolytic zinc	(L) Immersion	...	...	7 days	...	...	16.0	3.2		10
10 g/L $Na_2SO_4 \cdot 10H_2O$	Electrolytic zinc	(L) Immersion	...	...	14 days	...	...	16.0	3.2		10
Sulfamic acid											
3% solution	Sheet	(L) Immersion	20–25	68–76	48–95 h	...	...	...	2 200.0		1
3% solution	Galv. iron	(L) Immersion	20–25	68–76	48–95 h	...	...	...	2 280.0		1
3% solution	Sheet	(L) Immersion	66	150	4 h	...	...	...	2 340.0		1
6% solution	Sheet	(L) Immersion	20–25	68–76	48–95 h	...	...	...	2 200.0		1
6% solution	Galv. iron	(L) Immersion	20–25	68–76	48–95 h	...	...	...	2 280.0		1
12% solution	Sheet	(L) Immersion	20–25	68–76	48–95 h	...	...	...	7 800.0		1
12% solution	Galv. iron	(L) Immersion	20–25	68–76	48–95 h	...	...	...	1 400.0		1
20% solution	Sheet	(L) Immersion	20–25	68–76	48–95 h	...	...	...	730.0		1
20% solution	Galv. iron	(L) Immersion	20–25	68–76	48–95 h	...	...	...	910.0		1
Sulfur dioxide											
Liquid + 1% H_2O + 0.21% O_2	Sheet	(L) Immersion	20	68	14 days	...	...	30.0	6.0		27
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	2 h	...	...	604.0	121.0		28
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	4 h	...	...	465.0	93.0		28
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	7 h	...	...	314.0	63.0		28
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	24 h	...	...	92.0	18.0		28

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

(Continued)

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Table 9 (continued)

Corrosion medium	Material	Type of test(a)	Temperature °C	Temperature °F	Duration	Aeration	Agitation	Corrosion rate mg/dm²/day(b)	Corrosion rate mil/year	Remarks	Ref
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	72 h	. . .	. . .	34.7	7.0		28
0.6% vapors in air, 89% RH	99.6% Zn	(L) In vapors	40	104	168 h	. . .	. . .	18.4	4.0		28
Trichloroethylene											
Trichloroethylene	Sheet	(F) Immersion	. . .	. . .	41 h	. . .	. . .	289.0	58.0	In storage tank	1
Trichloroethylene vapors in air	Sheet	(F) In vapors	45	113	41 h	. . .	. . .	10.4	2.1	In dryer compartment	1
Trichloroethylene vapors in air	Sheet	(F) In vapors	84	183	41 h	. . .	. . .	13.6	2.7	In exhaust duct	1
Trichloroethylene vapors in air	Sheet	(F) In vapors	. . .	. . .	41 h	. . .	. . .	377.0	76.0	In still	1
Trichloroethylene, 100 cc	HG sheet	(L) Immersion	Room		4 months	None	None	Gained	. . .	Specimens only scrubbed before weighing, zinc attacked in water layer	17
Trichloroethylene, 100 cc	PW sheet	(L) Immersion	Room		4 months	. . .	. . .	Gained	. . .	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O	HG sheet	(L) Immersion	Room		4 months	None	None	3.08	0.6	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O	PW sheet	(L) Immersion	Room		4 months	None	None	4.53	0.9	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O + 0.15 g borax	HG sheet	(L) Immersion	Room		4 months	None	None	1.05	0.2	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O + 0.15 g borax	PW sheet	(L) Immersion	Room		4 months	None	None	0.25	<0.1	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O + 0.015 g $K_2Cr_2O_7$	HG sheet	(L) Immersion	Room		4 months	None	None	Gained	. . .	As above	17
Trichloroethylene, 95 cc + 15 cc distilled H_2O + 0.015 g $K_2Cr_2O_7$	PW sheet	(L) Immersion	Room		4 months	None	None	Gained	. . .	As above	17

(a) (L) laboratory test; (F) field test. (b) Unless otherwise indicated. Some corrosion rates are given in specialized units dictated by the test procedures used by the original investigators. The conversion to inches per year in some of these cases should not be considered representative of continuous immersion results, but should be evaluated in light of the test conditions. (c) Chromium in surface film, 0.02 μg/dm². (d) Chromium in surface film, 1.3 μg/dm². (e) Chromium in surface film, 2.2 μg/dm². (f) Chromium in surface film, 0.1 μg/dm². (g) Chromium in surface film, 0 μg/dm². (h) Chromium in surface film, 0.2 μg/dm²

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Tin and Tin Alloys

Tin is a soft, brilliant white, low-melting metal that is most widely used in the form of coatings for steel, that is, tinplate. In the molten state, it reacts with and readily wets most of the common metals and their alloys. Because of its low strength, the pure metal is not regarded as a structural material and is rarely used in monolithic form. Tin is also not used in manufactured articles due to its poor mechanical properties. Rather, the metal is frequently used as a coating for other metals and in alloys to impart corrosion resistance, enhance appearance, and improve solderability. It also finds wide use in alloys, especially tin-base soft solders, bearing alloys, and copper-base bronzes.

Allotropic Modification

In its usual form, tin has a specific gravity of 7.31 (white tin), but there is also a lighter metalloid modification with a specific gravity of 5.75, which exists as a gray powder (gray tin). White tin is stable at temperatures above 13 °C (55 °F). Gray tin is stable below 13 °C (55 °F). The maximum rate of transition of white into gray tin has been established at -48 °C (-54 °F). The allotropic transformation of white tin into gray tin is analogous to external corrosion.

In the past, when many domestic wares, munitions, and organ pipes were made of pure tin, such a transformation created much unpleasantness. Because initial transformation or contact with affected tin accelerated the transformation of healthy metal, the phenomenon received the name "tin disease." Pure tin is more susceptible to this deterioration than tin alloys. Tin alloys with 0.5% bismuth or antimony are not susceptible to transformation into gray tin at low temperatures.

Atmospheric Corrosion

In rural atmospheres, tin retains its bright appearance for many days. In one study, a light dulling was observed after 100 days, and a noticeable, faint yellow-gray tarnish film was seen after 150 days. However, it was also reported that the reflectivity of tin remains practically unchanged over long periods when the tin is washed in soap and water. Thus, at ordinary temperatures, the surface oxide film on tin is very thin and exhibits a very slow rate of growth. The rate of oxidation increases with temperature. Above 190 °C (375 °F), a film thickness sufficient to produce interference colors is reportedly produced in a few hours. At 210 °C (410 °F), this film thickness is produced in 20 min.

In marine and industrial environments, tin deteriorates. It does so at increasing rates, which depend on the aggressiveness of the specific environment.

Water Exposure

Tin maintains a high degree of stability in waters, particularly when they are soft or distilled. It is also quite stable in water containing CO_2 and also in solutions of neutral salts, such as chlorides and sulfates. It is very resistant to food materials and to various organic juices. For this reason, and because of its low toxicity and colorless corrosion products, tin is used extensively as a protective coating in food-processing equipment and in the canning industry as a protective coating for sheet iron. In fruit acids, tin has a more negative potential than iron; therefore, in the absence or deficiency of oxygen in sealed cans, rust does not form, despite the fact that the electroplated tin coating has some porosity. In atmospheric exposures, iron has a more electronegative potential than tin, and therefore, open tin cans rust rapidly in humid atmospheres.

Acids and Bases

The normal equilibrium potential of tin is -0.136 V and its static potential in 0.5*N* NaCl is -0.25 V. Susceptibility of tin to passivation is very low. Tin dissolves rapidly in nitric acid. It is unusable in alkalis. Tin corrodes in sulfuric and hydrochloric acids of medium-to-high concentrations. It is, however, resistant to dilute acids. Resistance to acids decreases as the accessibility of oxygen from air increases. Tin is very resistant to organic acids, although oxygen also promotes corrosive action.

Soft Solders

Most soft solders contain from about 2 to 98% tin; the balance consists mostly of lead. Two features are particularly relevant to the corrosion behavior of solders with regard to their function as a joining material. First, fluxes are usually used. Second, the solder exposure areas are usually smaller than the area of the materials being joined. By nature, fluxes function as oxide removers and may contain hygroscopic products that, if not removed, promote corrosion.

Nickel and Nickel Alloys

Nickel-base alloys generally are extremely effective corrosion-resistant materials in service environments that range from subzero to elevated temperatures. Nickel-base alloys are known for their ability to resist severe operating conditions involving liquid or gaseous environments, high stresses, and combinations of these factors. Nickel itself has good resistance to corrosion in reducing environments and can be used in oxidizing environments that act to promote the formation of a passive, corrosion-resistant oxide film. Nickel is highly resistant to caustic and chloride-ion-induced stress-corrosion cracking, is resistant to halide ions, and is an acceptable material for handling food. On the other hand, nickel is subject to both general and intercrystalline corrosion by compounds and gases that contain sulfur when the application temperature is greater than about 315 to 371 °C (600 to 700 °F). Nickel alloys may be similarly attacked, as for example by hot corrosion, where sulfur-containing compounds frequently promote the corrosive attack.

Nickel and its alloys have good resistance to corrosion in the normal atmosphere, in natural freshwaters, and in deaerated nonoxidizing acids. They also have excellent resistance to corrosion caused by caustic alkalis. Because nickel is a ductile, hardenable matrix, it forms the basis for a wide variety of strong and corrosion-resistant alloys. The most corrosion-resistant alloys for high-temperature applications are the nickel-base superalloys.

The principal elements used in nickel-base alloys are copper (as in the Monels) and chromium plus aluminum (as in superalloys such as the Hastelloy or Inconel/Incoloy materials). Chromium and aluminum provide elevated temperature oxidation resistance, and chromium and titanium provide resistance to hot corrosion. Other elements also are used to enhance oxidation/hot corrosion resistance. Chromium is a prime promoter of corrosion resistance in some liquid media at lower temperatures, but other alloy elements also are quite significant in the enhancement or promotion of corrosion resistance. Notable among the latter are copper, molybdenum, and tungsten. Other alloy elements are used to a considerable degree in nickel-base alloys, although not primarily for corrosion (or oxidation) resistance. Superalloys, in particular, may contain, intentionally, up to a dozen elements at controlled levels. The role of the major alloy element additions to nickel are summarized below.

Chromium

Chromium additions promote improved resistance of nickel to oxidizing acids such as nitric and chromic. Chromium also improves resistance to high-temperature oxidation in binary alloys, provided the chromium level exceeds about 5%. In practice, when chromium is the element providing oxidation resistance, a level of 20% or greater was found to be desirable for maximum corrosion protection. Some superalloys have been employed with chromium levels as low as about 8%, but these are all superalloys that use aluminum to form a protective aluminum oxide scale as the primary barrier to oxidation. Although alloys have been formulated with chromium levels up to 50%, customarily most corrosion- or oxidation-resistant alloys relying on chromium for primary environmental protection have contained about 15 to 30% chromium.

A principal role of chromium in modern superalloys has been to promote resistance to hot corrosion. Hot corrosion-resistant nickel-base alloys contain no less than about 14% chromium, and the most resistant alloys contain as much as 22%. Unfortunately for the designers of superalloys, enhanced strength is achieved by reducing the level of chromium so as to incorporate more of the hardening elements that contribute to the outstanding high-temperature strength of the nickel-base superalloys.

Copper

Copper has long been a prime alloying element with nickel, because the two elements are mutually soluble in one another. Each has good ductility and good corrosion resistance, along with the ability to be hardened. Additions of copper provide improvement in the resistance of nickel to nonoxidizing acids. In particular, alloys containing 30 to 40% copper offer useful resistance to nonaerated sulfuric acid and offer excellent resistance to all concentrations of nonaerated hydrofluoric acid. The Monel series of alloys are based on the 70% nickel/30% copper composition and are widely used in the

marine, chemical, petroleum, and process industries. Monel alloys are actually better suited to reducing than oxidizing conditions.

In addition to its role as a major alloying element, copper has been found to confer improved resistance to hydrochloric acid and phosphoric acid when 2 to 3% copper is added to nickel-chromium-molybdenum-iron alloys.

Molybdenum

Molybdenum in nickel substantially improves resistance to nonoxidizing acids. Commercial alloys for ambient temperature applications have employed up to 28% molybdenum for service in severe nonoxidizing solutions of hydrochloric, phosphoric, and hydrofluoric acids as well as in sulfuric acid. On the other hand, molybdenum, when used for elevated temperature strength, drastically degrades the hot corrosion resistance of nickel-base superalloys. Molybdenum in nickel superalloys rarely exceeds 6%. However, 9% molybdenum has been combined with 21.5% chromium, 3.5% niobium, and minor other elements in nickel to produce Inconel 625, a non-age-hardenable superalloy with outstanding resistance to reducing or oxidizing conditions. Molybdenum is thought to contribute as well, to the excellent resistance to stress-corrosion cracking and virtual immunity from crevice corrosion in chloride ion environments.

Tungsten

Tungsten behaves in a similar way to molybdenum, in that it degrades the hot corrosion resistance of superalloys, but provides improved resistance to nonoxidizing acids and to localized corrosion. Tungsten is not normally used unless absolutely necessary, because it significantly increases the density of alloys and their cost. Additions of tungsten in superalloys have been as high as 12%. Additions of 3 to 4% of the element, in conjunction with 13 to 16% molybdenum, have resulted in alloys with outstanding resistance to local corrosion.

Iron

Iron is not added to nickel to improve corrosion resistance, but rather to reduce costs. However, iron does provide nickel with improved resistance to sulfuric acid at concentrations above 50% sulfuric.

Silicon

Silicon typically is present in minor amounts as a residual element. In general, silicon is restricted to low levels to minimize processing problems and the potential for embrittling reactions in certain alloys. Under some circumstances, silicon has been intentionally added to promote the elevated temperature oxidation resistance of superalloys where it probably promotes scale retention of the protective oxides formed by chromium or aluminum. Silicon has been used as a major alloying element where resistance to hot sulfuric acid is desired. In those circumstances, 9 to 11% silicon has been used. Such materials are invariably processed as castings.

Aluminum

Aluminum is added to nickel-base alloys principally to produce high-temperature strength through the precipitation of the gamma prime phase in the nickel-chromium matrix. An unexpected benefit of the addition of aluminum was the formation of oxidation-resistant aluminum oxide scales on alloys containing greater than about 4% aluminum. One of the principal problems with the use of aluminum to achieve high-temperature oxidation resistance is that aluminum oxide formation is only conveniently achieved at elevated temperatures, probably above about 870 °C (1600 °F). For alloys operating below such temperatures, chromium provides better oxidation resistance, because the oxides are more likely to be self-healing. Pre-oxidation of aluminum-containing alloys will produce the necessary oxidation resistance for lower temperature operation, but if the protective aluminum oxide scale is abraded or removed in any way, the aluminum in the alloy will not produce the optimum oxidation resistance. Aluminum may actually be detrimental in promoting hot corrosion resistance in superalloys, depending on the level of chromium and aluminum in the alloy, as well as the temperature of exposure to hot corrosion-producing environments.

Titanium

Titanium is not added in any significant amounts to nickel alloys for lower temperature applications; if present, it can tie up carbon, nitrogen, or oxygen, which may be beneficial under some conditions of stress-enhanced corrosion. Titanium is found as a constituent of superalloys, where it acts similarly and in concert with aluminum to produce strength through gamma-prime hardening. Titanium appears to be beneficial for improved hot corrosion resistance, but no quantitative information is available. It is universally recognized that a high titanium-to-aluminum ratio is beneficial for improved hot corrosion resistance. However, the titanium benefit may decrease with increased temperature of hot corrosion attack.

Other elements

Other elements have been added or retained in nickel-base alloys to promote improved corrosion resistance. In particular, in nickel-base superalloys, active element additions such as yttrium, lanthanum, and others have been found to promote improved corrosion resistance, perhaps by increasing the scale retention characteristics. Tantalum has been found to promote elevated temperature oxidation resistance.

Additions of several percent tantalum to the alloy B-1900 or the single-crystal alloy PWA 1480 have resulted in several of the most oxidation-resistant superalloys used in commercial gas turbine applications. On the other hand, none of the above elements have had any significant role in the enhancement of lower temperature corrosion resistance of nickel-base alloys.

As with stainless steels, nickel-base alloys are susceptible to precipitation of a variety of phases (e.g., sigma, chi, etc.) and carbides that are detrimental to corrosion resistance. Therefore, processing and fabrication may have a profound impact on corrosion resistance.

Coatings

In general, nickel and nickel-base alloys are not coated for lower temperature corrosion protection. Nickel-base superalloys, on the other hand, are coated with aluminide diffusion coatings or overlay coatings that provide aluminum and chromium for protection against oxidation and hot corrosion. Aluminide coatings are produced by reacting aluminum with the substrate alloy to produce aluminum-rich nickel aluminide compounds on the surface of the alloy. Such coatings are customarily about 3 mils thick. Overlay coatings also rely on diffusion to achieve bonding; however, the coating contains all of the protective elements required for the application. Such coatings customarily are about 5 mils thick. Protectivity of the coatings is a function of the composition, thickness of the coating, and the exact nature of the environment in which the alloy/coating system will have to perform.

Selection for Corrosion Resistance

Selection for corrosion resistance is clearly a function of the intended application. High-temperature corrosion resistance is not the same as lower temperature, aqueous corrosion resistance. A steam turbine loop is not the same as an aircraft gas turbine, nor as the scrubber in a stack. Generally, the application will have to be evaluated in relation to the chemical interactions likely to take place and the cost of preventing corrosion. Corrosion curves will facilitate preliminary selection, but tests will also be necessary. Consultation with the appropriate manufacturer(s) and trade associations may help to finalize selection, but short-term tests will be required for validation of the selection. Long-term tests may be needed eventually. Nickel-base alloys will be more costly than copper alloys and stainless steels for applications, but their corrosion-resistant properties coupled with their other properties could make them cost-effective in the long run. For many applications, as in a gas turbine, no other alternate materials are available.

Cobalt-Base Alloys and Superalloys

The corrosion behavior of cobalt-base alloys, including superalloys, has not been as well documented as the behavior of nickel alloys. The two are similar in behavior, yet cobalt-base alloys possess somewhat less corrosion resistance in many instances. The relative resistance level is a function of the corroding medium, as well as the composition of the different alloy systems.

Cobalt cannot be classed as an oxidation-resistant material, although cobalt-base superalloys are quite resistant to oxidation and hot corrosion. The scaling and oxidation rates of unalloyed cobalt in air are reported to be 25 times those of nickel; in hot corrosion, however, cobalt-base superalloys may be an order of magnitude more resistant than nickel-base superalloys.

In lower temperature "aqueous" corrosion, the differences between cobalt alloys and nickel alloys may not be as significant. Alloy additions produce reversals of the inherent behavior of the basis metals, cobalt and nickel. In fact, cobalt-chromium alloys of the Vitallium type, which are basically cobalt-base superalloys, have been used successfully for many years as orthopedic implant materials under various trade names. It is reported that Vitallium can be repassivated within a few seconds after a scratch has been made in its surface, but that stainless steel, commonly used for short-term surgical procedures, is not repassivated as rapidly. (Testing was done in Hank's solution.)

Cobalt is superior to nickel in deaerated 6*N* hydrochloric acid at ambient temperatures, but the two metals have about the same resistance in aerated 1*N* hydrochloric acid. Nitric acid attacks cobalt more rapidly than it does nickel. Unfortunately, the published documentation on the corrosion resistance of cobalt and its alloys is minimal.

Cobalt alloys with chromium additions were discovered and exploited somewhat before comparable nickel alloys. Cobalt-chromium alloys have become standard materials for many applications, particularly those requiring corrosion resistance with wear resistance which in these alloys is achieved by high carbon content.

The principal alloying additions to cobalt are chromium and nickel, with the almost invariable presence of carbon as carbides to provide strength and wear resistance. Additionally, molybdenum and tungsten frequently are added to improve hot strength. Sometimes small amounts of other elements are added as well. For example, Haynes Alloy 188 contains about 0.15% lanthanum. These other elements include titanium, aluminum, and niobium. Not all of the above elements are intentionally added for the contribution that they make to corrosion resistance of cobalt alloys; all do produce some effect on corrosion resistance, either directly or indirectly.

Other Elements

The role of other alloying elements on the corrosion resistance of cobalt is even less clear than that of chromium. Most of the work reported concerns the effects of alloy additions on high-temperature oxidation resistance. The following effects are to be anticipated. However, interactions, both beneficial and detrimental, may occur when multiple alloy additions are present. Carbon may be deleterious because it ties up chromium. Vanadium, niobium, and molybdenum are harmful. Tungsten is more or less innocuous at temperatures below

about 980 °C (1800 °F), but it is harmful at temperatures above this level. Nickel may be slightly harmful, but manganese and iron may tend to be modestly beneficial. Titanium and zirconium have little effect. Active elements such as yttrium and lanthanum (in amounts less than about 0.5%) appear to be very beneficial, because they seem to improve scale adherence. The effects of aluminum have not been documented; it has been suggested that small aluminum additions may range in effect from innocuous to slightly beneficial. Under hot corrosion conditions, the above behavior may change.

Coatings

Protective coatings apparently are not used on cobalt and its alloys in lower temperature applications. In high-temperature applications, aluminide or overlay coatings have been developed, but are not regularly used. Aluminide coatings have been used on less oxidation-resistant alloys to improve oxidation resistance. Under prolonged exposure to oxidation or hot corrosion, coatings may be used to extend life. Corrosion protective coatings are never used in biological applications.

Selection for Corrosion Resistance

The guidelines for nickel-base alloys, noted elsewhere in this book, should be considered as background to this subject. Cobalt-base alloys have certain similarities involving corrosion resistance and other properties. In addition, there are differences, and these are not always apparent. Cobalt-base alloys are comparable to nickel-base alloys in cost, but prices fluctuate and must be reviewed at the appropriate time. Certainly, cobalt-base alloys will exceed the cost of copper-base alloys and stainless steel alloys. However, in many instances, the corrosion resistance and strength of cobalt-base alloys justify their use. Certainly, in biomaterial applications, cobalt-base alloys are substantially superior to stainless steels in performance. It should be recognized that there are far fewer cobalt-base alloys from which to select than there are available in the copper, nickel or stainless steel systems.

Cobalt alloys find use as hardfacing alloys, an application demanding wear resistance, high hardness, and reasonable corrosion resistance. They have been used in the chemical process industry, have been widely used in dentistry, have performed admirably in high-temperature service in piston and gas turbine engines, and have been the preeminent orthopedic implant material for many years.

Cobalt and its alloys probably are susceptible to the usual corrosion processes such as general corrosion and local corrosion, particularly pitting and crevice corrosion. Only a limited number of environments have been reported to cause stress-corrosion cracking in cobalt-base alloys. These include two general classes of environments — acid chlorides and strong alkalis. Moreover, both of these environments produce stress-corrosion cracking only at temperatures exceeding about 150 to 260 °C (300 to 500 °F). In general, the stress-corrosion cracking behavior of cobalt-base alloys is somewhat similar to that of nickel-base alloys.

Relative to the corrosion resistance of cobalt and its alloys, it should be noted that elemental cobalt undergoes an allotropic phase transformation on heating such that the lower temperature hexagonal crystal structure changes to the face-centered cubic structure (austenitic). Some credence has been attached to the fact that the austenitic structure is more resistant to corrosion attack than the hexagonal structure. When nickel is added in sufficient amounts to cobalt-chromium alloys, it stabilizes the austenitic structure. Consequently, any corrosion effects of nickel on cobalt-base alloys may have both chemical and crystallographic origins.

The principal use of cobalt-base alloys intended as corrosion-resistant materials has been the superalloys. These are cobalt-base alloys containing generally 20 to 30% chromium, less than about 0.7% carbon, along with varying amounts of nickel, molybdenum, and tungsten. The high chromium content is the major contributor to the oxidation and hot corrosion resistance of this class of materials.

Chromium

Chromium tends to confer lower temperature corrosion resistance, or high-temperature oxidation/hot corrosion resistance on cobalt by modifying the oxide film (scale). At high temperatures, the scale forms so as to produce a cobalt-chromium oxide spinel. In gaseous oxidizing environments, maximum oxidation resistance may not be reached until about 30% chromium has been added. This level may be contrasted with nickel-base alloys, which reach optimum oxidation resistance (owing to chromium) when the chromium level reaches about 20%. No information appears to be available on the chromium level necessary to produce atmospheric or biological corrosion resistance in cobalt alloys. However, in view of the fact that Vitallium has had over 50 years of successful application in dentistry and over 30 years of successful application in orthopedic surgery, it may be inferred that a minimum chromium level of 18% is needed.

Titanium and Titanium Alloys

Although highly reactive under certain conditions, titanium and titanium alloys are remarkably resistant to corrosion because of the formation of a stable, self-healing, oxide film that insulates the base material from the surrounding environment. As a consequence of its outstanding corrosion resistance at lower temperatures (in conjunction with other attractive properties such as low density and good

strength), titanium and its alloys find extensive use in applications ranging from chemical-processing operations to orthopedic implants. In a wide range of conditions, titanium is more resistant to lower temperature corrosion attack than stainless steels and copper alloys. Tables 10 and 11 provide general corrosion data for unalloyed titanium and titanium alloys respectively.

Unalloyed titanium is highly resistant to corrosion normally associated with many natural environments, including seawater, body fluids, and fruit and vegetable juices. Wet chlorine, molten sulfur, many organic compounds, and most oxidizing acids have essentially no effect on this metal. Titanium is used extensively for handling salt solutions, wet chlorine gas, and nitric acid solutions. Titanium and its alloys also resist H_2S and CO_2 gases at temperatures up to 260 °C (500 °F).

On the other hand, hot, concentrated, low-pH chloride salts corrode titanium; warm or concentrated solutions of hydrochloric, phosphoric, and oxalic acids also are damaging. In general, all acidic solutions that are reducing in nature corrode titanium, unless they contain inhibitors. Strong oxidizers, including anhydrous red fuming nitric acid and 90% hydrogen peroxide, also cause attack. Ionizable fluoride compounds, such as sodium fluoride and hydrogen fluoride, activate the surface and can cause rapid corrosion. Dry chlorine gas is especially harmful.

Most acidic solutions (except those containing soluble fluorides) can be inhibited by the presence of even small amounts of oxidizing agents and heavy metal ions. Thus, titanium can be used in certain industrial process solutions (including hydrochloric and sulfuric acids) that otherwise would be corrosive. Attack by red fuming nitric acid and chlorine gas can be inhibited by small amounts of water.

Because titanium metal itself has a high affinity for oxidation, the protective oxide film can reheal itself almost instantly when fresh metal surfaces are exposed to air or water. Anhydrous conditions in the absence of a source of oxygen may cause titanium to corrode, because the protective oxide film may not be able to be regenerated. The exact nature, composition, and thickness of the protective surface oxide films formed on titanium depends on the environmental conditions.

Successful application of titanium and its alloys can be expected in mildly reducing to highly oxidizing environments in which protective oxide films spontaneously form and remain stable. Titanium exhibits excellent resistance to atmospheric corrosion in both marine and industrial environments. Its resistance to seawater and to body fluids is virtually unsurpassed by that of any other structural metal.

Corrosion Resistance

The major corrosion problem with titanium alloys appears to be crevice corrosion, which occurs in locations where the corroding media are virtually stagnant. Pits, if formed, may progress in a similar manner.

Titanium alloys also may be subject to hot salt-induced stress-corrosion cracking or to accelerated crack propagation in seawater. Gaseous chloride ions and the presence of significant residual stress can promote stress-corrosion cracking. Titanium is regularly handled without danger of stress-corrosion cracking, and its use has been demonstrated in seawater, natural waters, and body fluids. However, at times, chlorides associated with fingerprints (in conjunction with subsequent heat, aqueous halides, and organic fluids such as methanol) have produced cracking. In the extreme, an unstressed Ti-5Al-5Sn-5Zr alloy, exposed to salt and placed in a furnace, reportedly cracked into multiple pieces in a short time due to the simultaneous presence of high residual stresses and salt. Most titanium alloys undergo stress-corrosion cracking in only certain specific environments.

Oxidizing chlorine compounds do not attack titanium alloys over the full range of compositions at lower temperatures. Stress-corrosion cracking is a function of microstructure as well as composition. Alpha titanium or high alpha alloys generally exhibit the greatest susceptibility, whereas beta titanium or beta-processed alpha-beta titanium alloys show less susceptibility. Thus the number of alpha, beta, and alpha-plus-beta alloys available display considerable variability in resistance to stress-corrosion cracking. Such alloys should be chosen with care.

Hot salt or aqueous stress-corrosion cracking phenomena are rarely encountered in the commercial application of titanium alloys. When hot salt stress-corrosion cracking occurs, it usually can be traced to improper design or processing.

Some titanium alloys crack under tensile stress when in contact with liquid cadmium, mercury, or silver-base brazing alloys. This liquid metal embrittlement differs from stress-corrosion cracking. Titanium also can be embrittled by contact with certain solid metals (cadmium and silver, for example) when it is under tensile stress. This attack may be similar to that for liquid metal embrittlement. Service failures have occurred in cadmium-plated titanium alloys at temperatures as low as 66 °C (150 °F).

Titanium alloys are not sufficiently strong to operate above about 538 °C (1000 °F), and thus the elevated temperature oxidation resistance of titanium alloys is rarely an issue. However, titanium alloys have limited oxidation resistance in air above about 650 °C (1200 °F). Titanium has a high affinity for the interstitial elements oxygen, nitrogen, and hydrogen; the dissolution of these elements in titanium alloys to any extent almost always results in embrittlement of the material. Newer titanium alloys based on the titanium aluminides may overcome this difficulty, but their commercial application is a decade away. Consequently, the majority of the corrosion data on titanium and its alloys are currently based on liquid media or gaseous atmospheres at ambient temperatures up to a few hundred degrees Fahrenheit.

For many chemical-processing applications, commercially pure titanium is used. When enhanced strength or corrosion resistance (or both) are required, alloy additions are made. In titanium alloy systems, corrosion resistance has not been the primary property of experimental interest; consequently, data on the effects of various alloying element additions on the corrosion resistance of titanium are limited.

Aluminum

In general, major alloy additions to titanium slightly degrade the corrosion resistance of the material. Aluminum is no exception; it is well known that the optimum chemical corrosion resistance is achieved with commercially pure titanium or in alloys with very minor elemental additions. Aluminum is an alpha phase promoter and is generally detrimental to stress-corrosion resistance, especially when the aluminum level exceeds about 6%. High aluminum concentrations may promote enhanced resistance to oxidation or oxygen embrittlement in titanium, but alloys of the titanium aluminide type are not yet commercially available.

Vanadium and Molybdenum

These refractory metals are found in most commercial titanium alloys and may exist in amounts from a fraction of a percent to over 12%. Little information exists to correlate corrosion behavior with the chemical changes produced by these elements. Their principal effect may lie in the changes that take place in the microstructure of titanium when these elements are used in any significant quantities. Because these elements favor the beta phase in titanium, they are not implicated in the stress-corrosion cracking of titanium alloys.

Other Elements

Minor amounts of other elements can affect the corrosion resistance of titanium. For example, the addition of a few tenths of a percent of palladium has been found to greatly improve the corrosion resistance of commercially pure titanium. Platinum and rhodium may provide the same effect, but they do so at a higher cost. The commercial alloy, Ti Code 12, which contains 0.3% molybdenum and 0.8% nickel, combines some of the favorable properties of nickel and molybdenum additions while avoiding the negative aspects. This alloy has excellent resistance to pitting and crevice corrosion in high-temperature brines, which sometimes attack commercially pure titanium. Small additions of molybdenum and nickel improve the resistance in reducing media such as hydrochloric and sulfuric acids, but the alloy additions are not as effective as the palladium additions mentioned above.

Alloys with modest nickel additions of about 2% have been developed and recommended for service in hot brine environments where crevice corrosion is sometimes a problem. Unfortunately, the addition of nickel tends to enhance the susceptibility of titanium to hydrogen embrittlement and also makes titanium difficult to fabricate.

Tin, added in amounts from 2 to 11%, is not intended to specifically enhance the corrosion properties of titanium. Although tin itself, along with manganese and cobalt, may be intrinsically detrimental to stress-corrosion cracking resistance, the ability of tin to replace aluminum may act to produce an overall improvement in stress-corrosion resistance of tin-containing titanium alloys.

In the area of rapidly solidified alloys, rare earth additions are being developed. The effects of such elements on lower temperature corrosion resistance have not been published; the principal applications of such alloys is expected to be at elevated temperatures.

Coatings

Titanium alloys are not coated to improve corrosion resistance. Wear- and abrasion-resistant coatings have been developed for select applications. Some aluminum coatings were developed to protect titanium alloys from hot salt stress-corrosion cracking, but there was little or no use of these coatings in practice.

Selection of Titanium Alloys for Corrosion Service

The selection of titanium or titanium alloys is best accomplished by observing that there are only two categories of titanium alloys—the essentially pure titaniums, which are largely used for lower temperature chemical and processing equipment, and the more highly alloyed titaniums, which are used in structural applications from the space shuttle to gas turbine engines. These latter types of alloys have been developed principally with strength as a primary criteria and corrosion resistance as a secondary or tertiary criteria. Microstructure is controlled to maximize corrosion resistance, especially hot salt corrosion resistance or seawater crack propagation resistance, after a specific composition has been selected.

For biomedical applications such as prosthetic devices, particularly in total hip replacement, selection consists of finding the optimum combination of corrosion resistance, fabricability, and strength. The standard commercial alloy, Ti-6Al-4V, possesses the best combination of these qualities. For other demanding corrosion-resistant applications at lower temperatures, there are only a limited number of titanium alloys available in the ASTM grade series. Moreover, there are a variety of proprietary alloys available from several manufacturers.

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Table 10 General Corrosion Data for Unalloyed Titanium

This table is a compilation of general corrosion rate values for unalloyed titanium (ASTM grades 1 to 4). These values were derived from published sources (Ref 1–8) and from unpublished in-house laboratory tests. These data should be used only as a guideline for alloy performance. Rates may vary depending on changes in medium chemistry, temperature, length of exposure, and other factors. Total alloy suitability cannot be assumed from these values alone, because other forms of corrosion, such as localized attack, may be limiting. In complex, variable, and/or dynamic environments, *in situ* testing may provide more reliable data.

Medium	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Acetaldehyde	75	149	0.001
	100	149	nil
Acetate, *n*-propyl	···	87	nil
Acetic acid	5–99.7	124	nil
	33–vapor	Boiling	nil
	99	Boiling	0.003
	65	121	0.003
	58	130	0.381
	99.7	124	0.003
Acetic acid + 3% acetic anhydride	Glacial	204	1.02
Acetic acid + 1.5% acetic anhydride	Glacial	204	0.005
Acetic acid + 109 ppm Cl	31.2	Boiling	0.259
Acetic acid + 106 ppm Cl	62.0	Boiling	0.272
Acetic acid + 5% formic acid	58	Boiling	0.457
Acetic anhydride	100	21	0.025
	100	150	0.005
	99.5	Boiling	0.013
Adipic acid + 15–20% glutaric + 2% acetic acid	25	199	nil
Adipic acid	67	240	nil
Adipylchloride and chlorobenzene solution	···	···	nil
Adiponitrile	Vapor	371	0.008
Aluminum chloride, aerated	10	100	0.002
	25	100	3.15
Aluminum chloride	10	100	0.002
	10	150	0.03
	25	60	nil
	25	100	6.55
Aluminum	Molten	677	164.6
Aluminum fluoride	Saturated	Room	nil
Aluminum nitrate	Saturated	Room	nil
Aluminum sulfate	Saturated	Room	nil
	10	80	0.05
	10	Boiling	0.12
Aluminum sulfate + 1% H_2SO_4	Saturated	Room	nil
Ammonium acid phosphate	10	Room	nil
Ammonium aluminum chloride	Molten	350–380	Very rapid attack
Ammonia, anhydrous	100	40	<0.127
Ammonia, steam, water	···	222	11.2
Ammonium acetate	10	Room	nil
Ammonium bicarbonate	50	100	nil
Ammonium bisulfite, pH 2.05	Spent pulping liquor	71	0.015
Ammonium carbamate	50	100	nil
Ammonium chloride	Saturated	100	<0.013
Ammonium chlorate	300 g/L	50	0.003
Ammonium fluoride	10	Room	0.102
Ammonium hydroxide	28	Room	0.003
	28	100	nil
Ammonium nitrate	28	Boiling	nil
Ammonium nitrate + 1% nitric acid	28	Boiling	nil
Ammonium oxalate	Saturated	Room	nil
Ammonium perchlorate	20	88	nil
Ammonium sulfate	10	100	nil
Ammonium sulfate + 1% H_2SO_4	Saturated	Room	0.010
Aniline	100	Room	nil
Aniline + 2% $AlCl_3$	98	158	>1.27
Aniline hydrochloride	5	100	nil
	20	100	nil
Antimony trichloride	27	Room	nil
Aqua regia	3:1	Room	nil
	3:1	80	0.86
	3:1	Boiling	1.12
Arsenous oxide	Saturated	Room	nil
Barium carbonate	Saturated	Room	nil
Barium chloride	5	100	nil
	20	100	nil
	25	100	nil
Barium hydroxide	Saturated	Room	nil
Barium nitrate	10	Room	nil
Barium fluoride	Saturated	Room	nil
Benzaldehyde	100	Room	nil
Benzene (traces of HCl)	Vapor and liquid	80	0.005
	Liquid	50	0.025
Benzene	Liquid	Room	nil
Benzoric acid	Saturated	Room	nil
Bismuth	Molten	816	High
Bismuth/lead	Molten	300	Good resistance
Boric acid	Saturated	Room	nil
	10	Boiling	nil
Bromine	Liquid	30	Rapid attack
Bromine, moist	Vapor	30	<0.003
Bromine gas, dry	···	21	Dissolves rapidly
Bromine-water solution	···	Room	nil
Bromine in methyl alcohol	0.05	60	0.03 (cracking possible)

(Continued)

Table 10 (continued)

Medium	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
N-butyric acid	Undiluted	Room	nil
Calcium bisulfite	Cooking liquor	26	0.001
Calcium carbonate	Saturated	Boiling	nil
Calcium chloride	5	100	0.005
	10	100	0.007
	20	100	0.015
	55	104	0.001
	60	149	<0.003
	62	154	0.406
	73	175	0.80
Calcium hydroxide	Saturated	Room	nil
	Saturated	Boiling	nil
Calcium hypochlorite	2	100	0.001
	6	100	0.001
	18	21	nil
	Saturated	21	nil
Carbon dioxide	100	. . .	Excellent
Carbon tetrachloride	99	Boiling	0.005
	Liquid	Boiling	nil
	Vapor	Boiling	nil
Carbon tetrachloride + 50% H_2O	50	25	0.005
Chlorine gas, wet	>0.7 H_2O	Room	nil
	>0.95 H_2O	140	nil
	>1.5 H_2O	200	nil
Chlorine saturated water	Saturated	97	nil
Chlorine gas, dry	<0.5 H_2O	Room	May react
Chlorine dioxide	5	82	<0.003
Chlorine dioxide + HOCl, H_2O + Cl_2	15	43	nil
Chlorine dioxide in steam	5	99	nil
Chlorine dioxide	10	70	0.03
Chlorine monoxide (moist)	Up to 15	43	nil
Chlorine trifluoride	100	30	Vigorous reaction
Chloracetic acid	30	82	<0.127
	100	Boiling	<0.127
Chlorosulfonic acid	100	Room	0.312
Chloroform	Vapor and liquid	Boiling	0.000
Chloroform + 50% H_2O	50	25	0.000
Chloropicrin	100	95	0.003
Chromic acid	10	Boiling	0.003
	15	24	0.006
	15	82	0.015
	50	24	0.013
	50	82	0.028
Chromic acid + 5% nitric acid	5	21	<0.003
Citric acid	10	100	0.009
	25	100	0.001
	50	60	0.000
	50	Boiling	0.127–1.27
	672	149	Corroded
Citric acid (aerated)	50	100	<0.127
Copper nitrate	Saturated	Room	nil
Copper sulfate	50	Boiling	nil
Copper sulfate + 2% H_2SO_4	Saturated	Room	0.018
Cupric carbonate + cupric hydroxide	Saturated	Ambient	nil
Cupric chloride	20	Boiling	nil
	40	Boiling	0.005
	55	118	0.003
Cupric cyanide	Saturated	Room	nil
Cuprous chloride	50	90	<0.003
Cyclohexylamine	100	Room	nil
Cyclohexane (plus traces of formic acid)	. . .	150	0.003
Dichloroacetic acid	100	Boiling	0.007
Dichlorobenzene + 4–5% HCl	. . .	179	0.102
Diethylene triamine	100	Room	nil
Ethyl alcohol	95	Boiling	0.013
	100	Room	nil
Ethylene dichloride	100	Boiling	0.005–0.127
Ethylene dichloride + 50% water	50	25	0.005
Ethylene diamine	100	Room	nil
Ferric chloride	10–20	Room	nil
	1–30	100	0.004
	10–40	Boiling	nil
	1–30	Boiling	nil
	50	150	0.003
Ferric chloride	10	Boiling	0.00
Ferric sulfate	10	Room	nil
Ferrous chloride + 0.5% HCl	30	79	0.006
Ferrous sulfate	Saturated	Room	nil
Fluoboric acid	5–20	Elevated	Rapid attack
Fluorine, commercial	Gas–liquid	Gas-109	0.864
Fluorine, HF free	Liquid	-196	0.011
	Gas	-196	0.011
Fluorosilicic acid	10	Room	47.5
Formaldehyde	37	Boiling	nil
Formamide vapor	. . .	300	nil
Formic acid, aerated	10	100	0.005
	25	100	0.001
	50	100	0.001
	90	100	0.001
Formic acid, nonaerated	10	100	nil
	25	100	2.44
	50	Boiling	3.20
	90	100	3.00
Formic acid	9	50	<0.127
Furfural	100	Room	nil
Gluconic acid	50	Room	nil
Glycerin	. . .	Room	nil
Hydrogen chloride, gas	Air mixture	25–100	nil
Hydrochloric acid, aerated	1	60	0.004
	2	60	0.016
	5	60	1.07
	1	100	0.46
	5	35	0.01
	10	35	1.02
	20	35	4.45
Hydrochloric acid	0.1	Boiling	0.10
	1	Boiling	1.8
Hydrochloric acid + 4% $FeCl_3$ + 4% $MgCl_2$	19	82	0.51
Hydrochloric acid + 4% $FeCl_3$ + 4% $MgCl_2$ + Cl_2 saturated	19	82	0.46
Hydrochloric acid, chlorine saturated	5	190	<0.025
	10	190	28.5
Hydrochloric acid, + 200 ppm Cl_2	36	25	0.432
Hydrochloric acid			
+1% HNO_3	5	40	nil
+1% HNO_3	5	95	0.091
+5% HNO_3	5	40	0.025
+5% HNO_3	5	95	0.030
+10% HNO_3	5	40	nil
+10% HNO_3	5	95	0.183
+3% HNO_3	8.5	80	0.051
+5% HNO_3	1	Boiling	0.074
Hydrochloric acid			
+2.5% $NaClO_3$	10.2	80	0.009
+5.0% $NaClO_3$	10.2	80	0.006
Hydrochloric acid			
+0.5% CrO_3	5	38	nil
+0.5% CrO_3	5	95	0.031
+1% CrO_3	5	38	0.018
+1% CrO_3	5	95	0.031
Hydrochloric acid			
+0.05% $CuSO_4$	5	38	0.040
+0.05% $CuSO_4$	5	93	0.091
+0.5% $CuSO_4$	5	38	0.091
+0.5% $CuSO_4$	5	93	0.061
+1% $CuSO_4$	5	38	0.031
+1% $CuSO_4$	5	93	0.091
+5% $CuSO_4$	5	38	0.020
+5% $CuSO_4$	5	93	0.061
+0.05% $CuSO_4$	5	Boiling	0.064
+0.5% $CuSO_4$	5	Boiling	0.084
Hydrochloric acid			
+0.05% $CuSO_4$	10	66	0.025
+0.20% $CuSO_4$	10	66	nil
+0.5% $CuSO_4$	10	66	0.023
+1% $CuSO_4$	10	66	0.023
+0.05% $CuSO_4$	10	Boiling	0.295
+0.5% $CuSO_4$	10	Boiling	0.290
Hydrochloric acid + 0.1% $FeCl_3$	5	Boiling	0.01
Hydrochloric acid + 1 g/L Ti^{4+}	10	Boiling	0.000
Hydrochloric acid + 5.8 g/L Ti^{4+}	20	Boiling	0.000

(Continued)

Table 10 (continued)

Medium	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Hydrochloric acid + 18% H_3PO_4 + 5% HNO_3	18	77	0.000
Hydrofluoric acid	1	26	127
Hydrofluoric acid, anhydrous	100	Room	0.127–1.27
Hydrofluoric-nitric acid 5 vol% HF-35 vol% HNO_3	...	25	452
Hydrofluoric-nitric acid 5 vol% HF-35 vol% HNO_3	...	35	571
Hydrogen peroxide	3	Room	<0.127
	6	Room	<0.127
	30	Room	<0.305
Hydrogen peroxide + 2% NaOH	1	60	55.9
Hydrogen peroxide			
pH 4	5	66	0.061
pH 1	5	66	0.152
pH 1	20	66	0.69
pH 11	0.08	70	0.42
Hydrogen sulfide (water saturated)	...	21	<0.003
Hydrogen sulfide, steam, and 0.077% mercaptans	7.65	93–110	nil
Hydroxy-acetic acid	...	40	0.003
Hypochlorous acid + ClO and Cl_2 gases	17	38	0.000
Iodine, dry or moist gas	...	25	0.1
Iodine in water + potassium iodide	...	Room	nil
Iodine in alcohol	Saturated	Room	Pitted
Lactic acid	10–85	100	<0.127
	10	Boiling	<0.127
Lead	...	816	Attacked
	...	324–593	Good
Lead acetate	Saturated	Room	nil
Linseed oil, boiled	...	Room	nil
Lithium, molten	...	316–482	nil
Lithium chloride	50	149	nil
Magnesium	Molten	760	Limited resistance
Magnesium chloride	5–20	100	<0.010
	5–40	Boiling	0.005
Magnesium hydroxide	Saturated	Room	nil
Magnesium sulfate	Saturated	Room	nil
Manganous chloride	5–20	100	nil
Maleic acid	18–20	35	0.002
Mercuric chloride	1	100	0.000
	5	100	0.011
	10	100	0.001
	Saturated	100	0.001
Mercuric cyanide	Saturated	Room	nil
Mercury	100	Up to 38	Satisfactory
	100	Room	nil
	...	371	3.03
Methyl alcohol	91	35	nil
	95	100	<0.01
Mercury + iron	...	371	0.079
Mercury + copper	...	371	0.063
Mercury + zirconium	...	371	0.033
Mercury + magnesium	...	371	0.083
Monochloracetic acid	30	80	0.02
	100	Boiling	0.013
Nickel chloride	5	100	0.004
	20	100	0.003
Nickel nitrate	50	Room	nil
Nitric acid, aerated	10	Room	0.005
	30	Room	0.004
	40	Room	0.002
	50	Room	0.002
	60	Room	0.001
	70	Room	0.005
	10	40	0.003
	20	40	0.005
	30	50	0.015
	40	50	0.016
	50	60	0.037
	60	60	0.040
	70	70	0.040
	40	200	0.610
	70	270	1.22
	20	290	0.305
Nitric acid	35	80	0.051–0.102
	70	80	0.025–0.076
	17	Boiling	0.076–0.102
	35	Boiling	0.127–0.508
	70	Boiling	0.064–0.900
Nitric acid, not refreshed	5–60	35	0.002–0.007
	5–60	60	0.01–0.02
	30–50	100	0.10–0.18
	5–20	100	0.02
	30–60	190	1.5–2.8
	70	270	1.2
	20	290	0.4
	70	290	1.1
Nitric acid, white fuming	Liquid or vapor	Room	nil
	...	82	0.152
	...	122	<0.127
	...	160	<0.127
Nitric acid, red fuming	<About 2% H_2O	Room	Ignition sensitive
	>About 2% H_2O	Room	Not ignition sensitive
Nitric acid	40	Boiling	0.63
+0.01% $K_2Cr_2O_7$	40	Boiling	0.01
+0.01% CrO_3	40	Boiling	0.01
+0.01% $FeCl_3$	40	Boiling	0.68
+1% $FeCl_3$	40	Boiling	0.14
+1% $NaClO_3$	40	Boiling	0.31
+1% $NaClO_3$	40	Boiling	0.02
+1% $Ce(SO_4)_2$	40	Boiling	0.10
+0.1% $K_2Cr_2O_7$	40	Boiling	0.016
Nitric acid, saturated with zirconyl nitrate	33–45	118	nil
Nitric acid + 15% zirconyl nitrate	65	127	nil
Nitric acid + 179 g/L $NaNO_3$ and 32 g/L NaCl	20.8	Boiling	0.127–0.295
Nitric acid + 170 g/L $NaNO_3$ and 2.9 g/L NaCl	27.4	Boiling	0.483–2.92
Oxalic acid	1	35	0.03
	5	35	0.13
	1	Boiling	107
	25	60	11.9
	Saturated	Room	0.508
Perchloroethylene + 50% H_2O	50	25	nil
Perchloryl fluoride + liquid ClO_3	100	30	0.002
Perchloryl fluoride + 1% H_2O	99	30	Liquid 0.290
	...	...	Vapor 0.003
Phenol	Saturated solution	25	0.102
Phosphoric acid	10–30	Room	0.020–0.051
	30–80	Room	0.051–0.762
	5.0	66	0.005
	6.0	66	0.117
	0.5	Boiling	0.094
	1.0	Boiling	0.266
	12	25	0.005
	20	25	0.076
	50	25	0.19
	9	52	0.03
	10	52	0.38
	5	Boiling	3.5
	10	80	1.83
Phosphoric acid + 3% nitric acid	81	88	0.381
Phosphorus oxychloride	100	Room	0.004
Phosphorus trichloride	Saturated	Room	nil
Photographic emulsions	...	...	<0.127
Phthalic acid	Saturated	Room	nil
Potassium bromide	Saturated	Room	nil
Potassium chloride	Saturated	Room	nil
	Saturated	60	nil
Potassium dichromate	Saturated	Room	nil
Potassium ethyl xanthate	10	Room	nil
Potassium ferricyanide	Saturated	Room	nil
Potassium hydroxide + 13% potassium chloride	13	29	nil
Potassium hydroxide	50	29	0.010
	10	Boiling	<0.127
	25	Boiling	0.305

(Continued)

Table 10 (continued)

Medium	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Potassium hydroxide	50	Boiling	2.74
	50 anhydrous	241–377	1.02–1.52
Potassium iodide	Saturated	Room	nil
Potassium permanganate	Saturated	Room	nil
Potassium perchlorate	20	Room	0.003
	0–30	50	0.003
Potassium sulfate	10	Room	nil
Potassium thiosulfate	1	Room	nil
Propionic acid	Vapor	190	Rapid attack
Pyrogallic acid	355 g/L	Room	nil
Salicylic acid	Saturated	Room	nil
Seawater	···	24	nil
Seawater, 4$^1/_2$-year test	···	Ambient	nil
Sebacic acid	···	240	0.008
Silver nitrate	50	Room	nil
Sodium	100	To 1100 (593)	Good
Sodium acetate	Saturated	Room	nil
Sodium aluminate	25	Boiling	0.091
Sodium bifluoride	Saturated	Room	Rapid
Sodium bisulfate	Saturated	Room	nil
	10	66	1.83
Sodium bisulfite	10	Boiling	nil
	25	Boiling	nil
Sodium carbonate	25	Boiling	nil
Sodium chlorate	Saturated	Room	nil
Sodium chlorate + NaCl 80–250 g/L	0–721 g/L	40	0.003
Sodium chloride	Saturated	Room	nil
pH 7	23	Boiling	nil
pH 1.5	23	Boiling	nil
pH 1.2	23	Boiling	0.71
pH 1.2, some dissolved chlorine	23	Boiling	nil
Sodium citrate	Saturated	Room	nil
Sodium cyanide	Saturated	Room	nil
Sodium dichromate	Saturated	Room	nil
Sodium fluoride	Saturated	Room	0.008
pH 7	1	Boiling	0.001
pH 10	1	Boiling	0.001
pH 7	1	204	0.000
Sodium hydrosulfide + sodium sulfide and polysulfides	5–12	110	<0.003
Sodium hydroxide	5–10	21	0.001
	10	Boiling	0.021
	28	Room	0.003
	40	80	0.127
	50	57	0.013
	50	Boiling	0.051
	73	129	0.178
	50–73	188	>1.09
	50	38	0.023
Sodium hypochlorite	6	Room	nil
Sodium hypochlorite + 15% NaCl + 1% NaOH	1.5–4	66–93	0.030
Sodium nitrate	Saturated	Room	nil
Sodium perchlorate	900 g/L	50	0.003
Sodium phosphate	Saturated	Room	nil
Sodium silicate	25	Boiling	nil
Sodium sulfate	10–20	Boiling	nil
	Saturated	Room	nil
Sodium sulfide	10	Boiling	0.027
	Saturated	Room	nil
Sodium sulfite	Saturated	Boiling	nil
Sodium thiosulfate	25	Boiling	nil
Sodium thiosulfate + 20% acetic acid	20	Room	nil
Soils, corrosive	···	Ambient	nil
Stannic chloride	5	100	0.003
	24	Boiling	0.045
Stannic chloride, molten	100	66	nil
Stannic chloride	100	35	nil
	Saturated	Room	nil
Steam + air	···	82	nil
Steam + 7.65% hydrogen sulfide	···	93–110	nil
Stearic acid, molten	100	180	0.003
Succinic acid	100	185	nil
	Saturated	Room	nil
Sulfanilic acid	Saturated	Room	nil
Sulfamic acid	3.75 g/L	Boiling	nil
	7.5 g/L	Boiling	2.74
Sulfamic acid + 0.375 g/L $FeCl_3$	7.5 g/L	Boiling	0.030
Sulfur, molten	100	240	nil
Sulfur monochloride	···	202	>1.09
Sulfur dioxide, dry	···	21	nil
Sulfur dioxide, water saturated	Near 100	Room	0.003
Sulfur dioxide gas + small amount SO_3 and approximately 3% O_2	18	316	0.006
Sulfuric acid, aerated	1	60	0.008
	3	60	0.013
	5	60	4.83
	10	35	1.27
	40	35	8.64
	75	35	1.07
	75	Room	10.8
	1	100	0.005
	3	100	23.4
	Concentrated	Room	1.57
	Concentrated	Boiling	5.38
	1	100	7.16
	3	100	21.1
Sulfuric acid	1	Boiling	17.8
	5	Boiling	25.4
Sulfuric acid + 0.25% $CuSO_4$	5	95	nil
	30	38	0.061
	30	95	0.088
Sulfuric acid + 0.5% $CuSO_4$	30	38	0.067
	30	95	0.823
Sulfuric acid + 1.0% $CuSO_4$	30	38	0.020
	30	95	0.884
Sulfuric acid + 0.5% CrO_3	5	95	nil
	30	95	nil
Sulfuric acid + 1.0% $CuSO_4$	30	Boiling	1.65
Sulfuric acid vapors	96	38	nil
	96	66	nil
	96	200–300	0.013
Sulfuric acid + 10% HNO_3	90	Room	0.457
Sulfuric acid + 50% HNO_3	50	Room	0.635
Sulfuric acid + 70% HNO_3	30	Room	0.102
Sulfuric acid + 90% HNO_3	10	Room	nil
Sulfuric acid + 90% HNO_3	10	60	0.011
Sulfuric acid + 95% HNO_3	5	60	0.005
Sulfuric acid + 50% HNO_3	50	60	0.399
Sulfuric acid + 20% HNO_3	80	60	1.59
Sulfuric acid saturated with chlorine	45	24	0.003
	62	16	0.002
	5, 10	190	<0.025
	82	50	>1.19
Sulfuric acid + 4 g/L Ti^{4+}	40	100	nil
Sulfurous acid	6	Room	nil
Tannic acid	25	100	nil
Tartaric acid	10–50	100	<0.127
	10	60	0.003
	25	60	0.003
	50	60	0.001
	10	100	0.003
	25	100	nil
	50	100	0.0121
Terephthalic acid	77	218	nil
Tetrachloroethane, liquid and vapor	100	Boiling	0.001
Tetrachloroethylene + H_2O	···	Boiling	0.127
Tetrachloroethylene	100	Boiling	nil
Tetrachloroethylene, liquid and vapor	100	Boiling	0.001
Titanium tetrachloride	99.8	300	1.57
Trichloroacetic acid	100	Boiling	14.6
Trichloroethylene	99	Boiling	0.003–0.127
Trichloroethylene + 50% H_2O	50	25	0.001
Uranium chloride	Saturated	21–90	nil
Uranyl ammonium phosphate filtrate + 25% chloride + 0.5% fluoride + 1.4% ammonia + 2.4% uranium	20.9	165	<0.003
Uranyl nitrate containing 25.3 g/L Fe^{3+}, 6.9 g/L Cr^{3+}, 2.8 g/L Ni^{2+}, 4.0 M HNO_3 + 1.0 M Cl	120 g/L	Boiling	nil
Uranyl sulfate + 3.1 M Li_2SO_4 + 100–200 ppm O_2	3.1 M	250	<0.020
Uranyl sulfate + 3.6 M Li_2SO_4, 50 psi oxygen	3.8 M	350	0.006–0.432

(Continued)

Table 10 (continued)

Medium	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Urea + 32% ammonia + 20.5% H_2O, 19% CO_2	28	182	0.079
Water, degassed	...	316	nil
Water, river, saturated with chlorine	...	93	nil
X-ray developer solution	...	Room	nil
Zinc chloride	5	Boiling	nil
	20	104	nil
	50, 75	150	nil
	75	150	0.06
	75	200	Rapid pitting
	80	173	2.1
Zinc sulfate	Saturated	Room	nil

Table 11 General Corrosion Data for Titanium Alloys

This table is a compilation of general corrosion rate values for commercial titanium alloys other than the unalloyed grades. These values were derived from published sources (Ref 2, 4, 7, 9–12) and from unpublished in-house laboratory tests. These data should be used only as a guideline for alloy performance. Rates may vary depending on changes in medium chemistry, temperature, length of exposure, and other factors. Total alloy suitability cannot be assumed from these values alone, because other forms of corrosion, such as localized attack, may be limiting. In complex, variable, and/or dynamic environments, *in situ* testing may provide more reliable data.

Medium	Alloy	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Acetic acid	Grade 9	99.7	Boiling	nil
Acetic acid + 5% formic acid	Grade 12	58	Boiling	nil
Ammonium hydroxide	Grade 12	30	Boiling	nil
Aluminum chloride	Grade 12	10	Boiling	nil
	Grade 7	10	100	<0.025
	Grade 7	25	100	0.025
Ammonium chloride	Grade 12	10	Boiling	nil
Ammonium hydroxide	Grade 9	8, 28	150	nil
Aqua regia	Grade 7	3:1	Boiling	1.12
	Grade 12	3:1	Boiling	0.61
	Grade 9	3:1	Boiling	1.29
	Grade 9	3:1	25	0.015
Calcium chloride	Grade 7	62	150	nil
	Grade 7	73	177	nil
Chlorine, wet	Grade 7	...	25	nil
Chromic acid	Grade 7	10	Boiling	nil
	Grade 9	10	Boiling	0.008
	Grade 9	30	Boiling	0.053
	Grade 9	50	Boiling	0.26
Citric acid	Grade 7	50	Boiling	0.025
	Grade 12	50	Boiling	0.013
	Grade 9	50	Boiling	0.38
Ferric chloride	Grade 7	10	Boiling	nil
	Grade 12	10	Boiling	nil
	Ti-5Ta	10	Boiling	nil
	Grade 7	30	Boiling	nil
	Ti-6-4	10	Boiling	nil
	Ti-3-8-6-4-4	10	Boiling	nil
	Ti-10-2-3	10	Boiling	nil
	Ti-6-2-4-6	10	Boiling	0.06
	Transage 207	10	Boiling	0.19
	Ti-550	10	Boiling	nil
	Grade 9	10	Boiling	nil
	Ti-6-2-1-.8	10	Boiling	nil
Formic acid	Grade 9	25	88	<0.13
Formic acid, nitrogen-sparged	Grade 9	25	35	<0.13
Formic acid	Grade 9	50	Boiling	5.08
	Grade 7	45	Boiling	nil
	Grade 12	45, 50	Boiling	nil
	Grade 7	50	Boiling	0.01
	Ti-6-4	50	Boiling	7.92
	Transage 207	50	Boiling	0.90
	Ti-6-2-4-6	50	Boiling	0.62
	Ti-3-8-6-4-4	50	Boiling	0.98
	Ti-5Ta	50	Boiling	3.16
	Ti-550	50	Boiling	0.02
	Grade 12	90	Boiling	0.56
	Grade 7	90	Boiling	0.056
Hydrochloric acid	Ti-550	0.5	Boiling	0.056
	Ti-550	1.0	Boiling	0.64
	Transage 207	0.5	Boiling	0.005
	Transage 207	1.0	Boiling	0.025
	Ti-6-2-4-6	0.5	Boiling	nil
	Ti-6-2-4-6	1.0	Boiling	0.03
Hydrochloric acid, aerated	Ti-6-2-4-6	pH 1	Boiling	0.01
Hydrochloric acid	Ti-10-2-3	0.5	Boiling	1.10
	Ti-3-8-6-4-4	0.5	Boiling	0.003
	Ti-3-8-6-4-4	1.0	Boiling	0.058
	Ti-3-8-6-4-4	1.5	Boiling	0.26
Hydrochloric acid, aerated	Ti-3-8-6-4-4	pH 1	Boiling	nil
Hydrochloric acid	Ti-5Ta	0.5	Boiling	0.013
	Ti-5Ta	1.5	Boiling	2.10
	Ti-6-4	1.0	Boiling	2.52
Hydrochloric acid, aerated	Ti-6-4	pH 1	Boiling	0.60
Hydrochloric acid	Grade 9	0.5	Boiling	1.08
	Grade 9	1	88	0.009
	Grade 9	3	88	3.10
Hydrochloric acid, deaerated	Grade 7	3	82	0.013
	Grade 7	5	82	0.051
	Grade 7	10	82	0.419
Hydrochloric acid	Grade 9	1	Boiling	2.79
Hydrochloric acid, aerated	Grade 9	5	35	0.001
Hydrochloric acid, nitrogen saturated	Grade 9	5	35	0.185
Hydrochloric acid	Ti-6-2-1-.8	0.5	Boiling	0.020
	Ti-6-2-1-.8	1.0	Boiling	1.07
	Grade 7	0.5	Boiling	nil
	Grade 7	1.0	Boiling	0.008
	Grade 7	1.5	Boiling	0.03
	Grade 7	5.0	Boiling	0.23
	Grade 12	0.5	Boiling	nil
	Grade 12	1.0	Boiling	0.04
	Grade 12	1.5	Boiling	0.25
Hydrochloric acid, hydrogen saturated	Grade 7	1–15	25	<0.025
	Grade 7	20	25	0.102
	Grade 7	5	70	0.076
	Grade 7	10	70	0.178
	Grade 7	15	70	0.33
	Grade 7	3	190	0.025
	Grade 7	5	190	0.102
	Grade 7	10	190	8.9
Hydrochloric acid, oxygen saturated	Grade 7	3, 5	190	0.127
	Grade 7	10	190	9.3
Hydrochloric acid, chlorine saturated	Grade 7	3, 5	190	<0.03
	Grade 7	10	190	29.0

(Continued)

Table 11 (continued)

Medium	Alloy	Concentration, %	Temperature, °C	Corrosion rate, mm/yr
Hydrochloric acid, aerated	Grade 7	1, 5	70	<0.03
	Grade 7	10	70	0.05
	Grade 7	15	70	0.15
Hydrochloric acid + 4% $FeCl_3$ + 4% $MgCl_2$	Grade 7	19	82	0.49
Hydrochloric acid + 4% $FeCl_3$ + 4% $MgCl_2$, chlorine saturated	Grade 7	19	82	0.46
Hydrochloric acid				
+5 g/L $FeCl_3$	Grade 7	10	Boiling	0.279
+16 g/L $FeCl_3$	Grade 7	10	Boiling	0.076
+16 g/L $CuCl_2$	Grade 7	10	Boiling	0.127
Hydrochloric acid				
+2 g/L $FeCl_3$	Grade 12	4.2	91	0.058
+0.2% $FeCl_3$	Grade 9	1	Boiling	0.005
+0.2% $FeCl_3$	Grade 9	5	Boiling	0.033
+0.2% $FeCl_3$	Grade 9	10	Boiling	0.305
+0.1% $FeCl_3$	Grade 9	5	Boiling	0.008
+0.1% $FeCl_3$	Ti-550	5	Boiling	0.393
+0.1% $FeCl_3$	Transage 207	5	Boiling	0.048
+0.1% $FeCl_3$	Ti-6-2-4-6	5	Boiling	0.068
+0.1% $FeCl_3$	Ti-10-2-3	5	Boiling	0.008
+0.1% $FeCl_3$	Ti-3-8-6-4-4	5	Boiling	0.018
+0.1% $FeCl_3$	Ti-5Ta	5	Boiling	0.020
+0.1% $FeCl_3$	Ti-6-4	5	Boiling	0.015
+0.1% $FeCl_3$	Ti-6-2-1.-.8	5	Boiling	0.051
+0.1% $FeCl_3$	Grade 7	5	Boiling	0.013
+0.1% $FeCl_3$	Grade 12	5	Boiling	0.020
Hydrochloric acid + 18% H_3PO_4 + 5% HNO_3	Grade 7	18	77	nil
Hydrogen peroxide				
pH 1	Grade 7	5	23	0.062
pH 4	Grade 7	5	23	0.010
pH 1	Grade 7	5	66	0.127
pH 4	Grade 7	5	66	0.046
+500 ppm Ca^{2+}, pH 1	Grade 7	5	66	nil
+500 ppm Ca^{2+}, pH 1	Grade 7	20	66	0.76
Hydrogen peroxide, pH 1 + 5% NaCl	Grade 7	20	66	0.008
Magnesium chloride	Grade 7	Saturated	Boiling	nil
Methyl alcohol	Grade 9	99	Boiling	nil
Oxalic acid	Grade 7	1	Boiling	1.14
Nitric acid	Grade 9	10	Boiling	0.084
	Grade 9	30	Boiling	0.497
Phosphoric acid, naturally aerated	Grade 12	25	25	0.019
	Grade 12	30	25	0.056
	Grade 12	45	25	0.157
	Grade 12	8	52	0.02
	Grade 12	13	52	0.066
	Grade 12	15	52	0.52
	Grade 12	5	66	0.038
	Grade 12	7	66	0.15
	Grade 12	0.5	Boiling	0.071
	Grade 12	1.0	Boiling	0.14
	Grade 7	40	25	0.008
	Grade 7	60	25	0.07
	Grade 7	15	52	0.036
	Grade 7	23	52	0.15
	Grade 7	8	66	0.076
	Grade 7	15	66	0.104
	Grade 7	0.5	Boiling	0.050
	Grade 7	1.0	Boiling	0.107
	Grade 7	5.0	Boiling	0.228
Potassium hydroxide	Grade 9	50	150	9.21
Seawater	Grade 9	...	Boiling	nil
Sodium chloride, pH 1	Grade 9	Saturated	93	nil
Sodium fluoride				
pH 7	Grade 12	1	Boiling	0.001
pH 7	Grade 7	1	Boiling	0.002
Sodium hydroxide	Grade 9	50	150	0.49
Sodium sulfate, pH 1	Grade 7	10	Boiling	nil
Sulfamic acid	Grade 12	10	Boiling	11.6
	Grade 7	10	Boiling	0.37
Sulfuric acid, naturally aerated	Grade 12	9	24	0.003
	Grade 12	9.5	24	0.006
	Grade 12	10	24	0.38
	Grade 12	3.5	52	0.013
	Grade 12	3.75	52	1.73
	Grade 12	2.75	66	0.015
	Grade 12	3.0	66	1.65
	Grade 12	0.75	Boiling	0.003
	Grade 12	1.0	Boiling	0.91
	Grade 7	1.0	204	0.005
	Grade 7	2.0	204	nil
	Grade 12	1.0	204	0.91
	Grade 9	0.5	Boiling	8.48
Sulfuric acid, nitrogen saturated	Grade 7	5	70	0.15
	Grade 7	10	70	0.25
	Grade 7	1, 5	190	0.13
	Grade 7	10	190	1.50
Sulfuric acid, oxygen saturated	Grade 7	1–10	190	0.13
Sulfuric acid, chlorine saturated	Grade 7	10	190	0.051
	Grade 7	20	190	0.38
Sulfuric acid, nitrogen saturated	Grade 7	10	25	0.025
	Grade 7	40	25	0.23
Sulfuric acid, aerated	Grade 9	5	35	0.025
Sulfuric acid, nitrogen saturated	Grade 9	5	35	0.405
Sulfuric acid, naturally aerated	Ti-3-8-6-4-4	1	Boiling	nil
	Ti-3-8-6-4-4	5	Boiling	1.85
Sulfuric acid, aerated	Grade 7	10	70	0.10
	Grade 7	40	70	0.94
Sulfuric acid + 5 g/L $Fe_2(SO_4)_3$	Grade 7	10	Boiling	0.178
Sulfuric acid + 16 g/L $Fe_2(SO_4)_3$	Grade 7	10	Boiling	<0.03
Sulfuric acid + 16 g/L $Fe_2(SO_4)_3$	Grade 7	20	Boiling	0.15
Sulfuric acid + 15% $CuSO_4$	Grade 7	15	Boiling	0.64
Sulfuric acid + 3% $Fe_2(SO_4)_3$	Ti-3-8-6-4-4	50	Boiling	<0.03
Sulfuric acid + 1 g/L $FeCl_3$	Ti-3-8-6-4-4	10	Boiling	0.15
Sulfuric acid + 50 g/L $FeCl_3$	Ti-3-8-6-4-4	10	Boiling	0.05
Sulfuric acid + 1% $CuSO_4$	Grade 7	30	Boiling	1.75
Sulfuric acid + 100 ppm Cu^{2+} + 1% thiourea (deaerated)	Grade 7	1	100	nil
Sulfuric acid + 100 ppm Cu^{2+} + 1% thiourea (deaerated)	Grade 12	1	100	0.23
Sulfuric acid + 1000 ppm Cl^-	Grade 7	15	49	0.015

Zirconium

Zirconium is a reactive metal and has a high affinity for oxygen. When it is exposed to an oxygen-containing environment, an adherent, protective oxide film forms on its surface. This film occurs spontaneously in air or water at ambient temperature and below. Moreover, the film is self-healing and protects the base metal from chemical and mechanical attack at temperatures up to 300 °C (570 °F). Consequently, zirconium is very resistant to corrosive attack in most mineral and organic acids, strong alkalis, saline solutions, and some molten salts. Zirconium is not attacked by oxidizing media unless halides are present. The corrosion properties are unaffected as long as this thin layer is not penetrated by reactants at increasing temperatures. Table 12 gives the corrosion resistance of zirconium alloys in various media.

Water

Zirconium does not experience any appreciable attack by water at ordinary temperatures. However, its resistance to both water and steam is markedly affected by impurities such as nitrogen, aluminum, and titanium. Dissolved ferric and cupric chlorides, even in small concentrations, increase the attack.

In high-temperature water, zirconium and many of its alloys show a period of decreasing corrosion followed by a transition to a more rapid linear rate. The time to transition, along with the subsequent rate of attack, varies with purity and with temperature. The corrosion is extremely sensitive to dissolved nitrogen. More than 40 ppm causes a rapid transition to a high rate of corrosion. In like fashion, even small amounts of titanium and aluminum cause deleterious effects. Alloys such as Zircaloy 2 and Zircaloy 4, which contain small amounts of tin, iron, and chromium, rate much better in high-temperature water with respect to corrosion resistance.

Salt Water

Zirconium has excellent resistance to seawater, brackish water, and polluted water. The corrosion properties of Zr702 in natural seawater have been tested. All welded and nonwelded specimens exhibited negligible corrosion rates. Although marine befouling was observed, no corrosion was found beneath the marine organisms. Alloys Zr702 and Zr704, after extensive laboratory and sea testing, demonstrated resistance to general, pitting, and crevice corrosion.

Acids

Zirconium is very resistant to corrosive attack in most mineral and organic acids, strong alkalines, saline solutions, and some molten salts. Most important, historically speaking, it has excellent corrosion-resistant qualities in the presence of hydrochloric acid. There is some evidence of an increment in corrosion due to intergranular penetration when zirconium is exposed to HCl at 200 °C (390 °F) under pressure. However, zirconium is totally resistant to attack in all concentrations of HCl to temperatures well above boiling.

Zirconium has excellent corrosion resistance to HNO_3. This extends from below boiling at 98% HNO_3 up to 250 °C (480 °F) with a 70% concentration.

There are, however, a few media that will attack zirconium. Among them are hydrofluoric acid (HF), ferric chloride ($FeCl_3$), cupric chloride ($CuCl_2$), aqua regia, concentrated sulfuric acid (H_2SO_4), and wet chlorine gas. Zirconium resists attack by H_2SO_4 at all concentrations up to 70% and to temperatures to boiling and above, although the level of resistance depends strongly on temperature.

Organic Media

Zirconium resists corrosion over a wide range of organic compounds, including acetic acid, acetic anhydride, formic acid, urea, ethylene dichloride, formaldehyde, citric acid, lactic acid, tannic acid, and trichloroethylene.

Hafnium

Hafnium occurs naturally in zirconium, and the two are considered "sister" elements. It shares many common properties with zirconium, especially its high corrosion resistance to many media. Hafnium has chemical and metallurgical properties similar to those of zirconium, although its nuclear properties are markedly different. Hafnium has a high thermal neutron absorption cross section in contrast to the very low absorption cross section of zirconium. This quality has made it a primary material for nuclear reactor rods.

Nuclear Grades

As the result of this essential difference between zirconium and hafnium, there are both nuclear and non-nuclear grades of zirconium and zirconium alloys. The nuclear grades are essentially hafnium free; the non-nuclear (i.e., industrial application) grades may contain up to 4.5% hafnium. Nuclear grades also have improved corrosion resistance in waters above 290 °C (550 °F).

Zircaloy, Zr-2.5Nb, and Zr-1Nb are nuclear grade materials. Of the well-known Zircaloy group of alloys now generally used in nuclear reactors, Zircaloy 2 and Zircaloy 4 contain small amounts of tin, iron, and chromium. They therefore have improved corrosion resistance in waters above 290 °C (554 °F).

ASTM specifications for non-nuclear grades list UNS R60704 as the alloy corresponding closely to Zircaloy 4, and UNS R60705 and R60706 as the alloys corresponding closely to Zr-2.5Nb. Alloys known by ASTM grades 702 and 705 are the most important for industrial applications.

In aqueous solutions, hafnium is soluble in hydrofluoric acid (HF) and concentrated H_2SO_4. It is resistant to dilute HCl and H_2SO_4 and is unaffected by HNO_3 in all concentrations. Aqua regia dissolves hafnium, and with the addition of small amounts of soluble fluoride salts, the reaction with other acids is appreciably increased. Hafnium is also very resistant to alkalis.

Corrosion Testing

Because the behavior of zirconium is often negatively influenced by impurities in corrosive environments, corrosion testing prior to use should be carried out in actual plant liquors rather than in purer synthetic solutions created in the laboratory.

Table 12 Corrosion Resistance of Zirconium Alloys in Various Media

Medium	Concentration, %	Temperature °C	Temperature °F	Corrosion rate Zr702 mm/yr	Zr702 mils/yr	Zr704 mm/yr	Zr704 mils/yr	Zr705 mm/yr	Zr705 mils/yr	Remarks
Acetaldehyde	100	Boiling		<0.05	<2	...	...	...	...	...
Acetic acid	5–99.5	35	95 to boiling	<0.025	<1	...	...	<0.025	<1	...
Acetic acid anhydride	99	Room-boiling		<0.025	<1	...	...	<0.025	<1	...
Acetic acid (glacial)	99.7	Boiling		<0.13	<5	...	...	...	...	...
Acetic acid	100	160	320	<0.025	<1	...	...	...	...	...
Acetic acid + 50 ppm I^-	100	160,200	320,390	<0.025	<1	...	...	...	...	...
Acetic acid + 1% I^- + 100 ppm Fe^{3+}	99	200	390	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI	80	100	212	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI + 1000 ppm iron added as powder	80	100	212	<0.025	<1	...	...	...	...	...
Acetic acid + 2% HI, 1% methanol, 500 ppm formic acid, 100 ppm Cu	80	150	300	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI, 1% methanol, 500 ppm formic acid, 100 ppm Fe	80	150	300	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI	98	150	300	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI + 200 ppm Cl^-	80	100	212	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI + 200 ppm Fe^{3+}	80	100	212	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% I^-	98	150	300	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI + 1% CH_3OH + 500 ppm formic acid	80	150	300	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 2% HI + 200 ppm Cl^-	80	100	212	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 50% acetic anhydride	50	Boiling		<0.025	<1	...	...	<0.025	<1	...
Acetic acid + 50% 48% HBr	50	115	240	<0.025	<1	...	...	<0.025	<1	...
Acetic acid + saturated gaseous HCl and Cl_2	100	Boiling		>5	>200	...	...	>5	>200	...
Acetic acid + saturated, gaseous HCl and Cl_2	100	40	100	<0.025	<1	...	...	...	...	...
Acetic acid + 10% CH_3OH	90	200	390	<0.025	<1	...	...	...	...	...
Aluminum chlorate	30	100	212	<0.05	<2	...	...	...	...	...
Aluminum chloride	5, 10, 25	35–100	95–212	<0.025	<1	...	...	...	...	...
	25	Boiling		<0.025	<1	...	...	<0.025	<1	...
	40	100	212	<0.05	<2	...	...	...	...	...
Aluminum chloride (aerated)	5, 10	60	140	<0.05	<2	...	...	...	...	...
Aluminum fluoride	20	Room		>1.3	>50	...	...	...	...	pH 3.2
Aluminum potassium sulfate	10	Boiling		nil		...	...	nil		pH 3.2
Aluminum sulfate	25	Boiling		nil		...	...	nil		...
	60	100	212	<0.05	<2	...	...	...	...	...
Ammonia (wet)	$+H_2O$	38	100	<0.13	<5	...	...	...	...	...
Ammonium carbamate		193	380	<0.025	<1	...	...	...	...	58.4% urea, 16.8% ammonia, 14.8% CO_2, 9.9% H_2O at 22–24 MPa (3200–3500 psi)
Ammonium chloride	1, 10, saturated	35–100	95–212	<0.025	<1	...	...	...	...	...
Ammonium hydroxide	28	Room to 100	212	<0.025	<1	...	...	...	...	...
Ammonium fluoride	20	28	80	>1.3	>50	...	...	...	...	pH 8
	20	98	210	>1.3	>50	...	...	...	...	pH 8
Ammonium oxalate	100	100	212	<0.05	<2	...	...	...	...	...
Ammonium sulfate	5, 10	100	212	<0.13	<5	...	...	...	...	...
Aniline hydrochloride	5, 20	35–100	95–212	<0.025	<1	...	...	...	...	...
	5, 20	100	212	<0.05	<2	...	...	...	...	...
Aqua regia	3:1	Room		>1.3	>50	...	...	...	...	3 parts HCl/1 part HNO_3
Barium chloride	5.20	35–100	95–212	<0.025	<1	...	...	...	...	...
	25	Boiling		0.13–0.25	5–10	...	...	...	...	...

(Continued)

Table 12 (continued)

Medium	Concentration, %	Temperature °C	Temperature °F	Corrosion rate Zr702 mm/yr	Zr702 mils/yr	Zr704 mm/yr	Zr704 mils/yr	Zr705 mm/yr	Zr705 mils/yr	Remarks
Bromine	100-liquid	20	70	<0.25	<10	...	...	0.5–1.3	20–50	Pitting
	vapor	20	70	...	...	...	...	>1.3	>50	Pitting
Bromochloromethane	100	100	212	<0.05	<2	...	...	...	...	...
Cadmium chloride	100	Room		<0.05	<2	...	...	...	...	...
Calcium bromide	100	100	212	<0.05	<2	...	...	...	...	...
Calcium chloride	5, 10, 25	35–100	95–212	<0.025	<1	...	...	...	...	...
	70	Boiling		<0.025	<1	...	...	<0.025	<1	B.P. = 162 °C (324 °F)
	75	Boiling		<0.13	<5	...	...	...	...	...
	Mixture	79	175	<0.025	<1	...	...	...	...	14% CaCl, 8% NaCl, 0.2% $Ca(OH)_2$
Calcium fluoride	Saturated	28	80	nil		...	...	...	...	pH 5
	Saturated	90	195	nil		...	...	...	...	pH 5
Calcium hypochlorite	2, 6, 20	100	212	<0.13	<5	...	...	...	...	...
Carbonic acid	Saturated	100	212	<0.13	<5	...	...	...	...	...
Carbon tetrachloride	0–100	Room to 100	212	<0.13	<5	...	...	...	...	...
Chlorine (water saturated)		Room		>1.3	>50	...	...	...	...	...
		75	165	>1.3	>50	...	...	...	...	...
Chlorine gas (more than 0.13% H_2O)	100	94	200	>1.3	>50	...	...	...	...	...
Chlorine gas (dry)	100	Room		<0.13	<5	...	...	...	...	...
Chlorinated water		100	212	<0.05	<2	...	...	...	...	...
Chloroacetic acid	100	Boiling		<0.025	<1	...	...	...	...	...
Chromic acid	10–50	Boiling		<0.025	<1	...	...	...	...	...
Citric acid	10–50	35–100	95–212	<0.025	<1	...	...	...	...	...
	10, 25, 50	100	212	<0.025	<1	...	...	...	...	...
	50	Boiling		<0.13	<5	...	...	...	...	...
Chromium plating solution		66	150	>1.3	>50	...	...	>1.3	>50	M + T chemicals CR-100
Cupric chloride	5, 10, 20	35–100	95–212	>1.3	>50	>1.3	>50	>1.3	>50	...
	20, 40, 50	Boiling		>1.3	>50	>1.3	>50	>1.3	>50	...
Cupric cyanide	Saturated	Room		>1.3	>50	...	...	...	...	...
Cupric nitrate	40	Boiling		Weight gain		...	...	Weight gain		B.P. = 115 °C (239 °F)
Dichloroacetic acid	100	Boiling		<0.5	<20	...	...	...	...	...
Ethylene dichloride	100	Boiling		<0.13	<5	...	...	...	...	...
Ferric chloride	0–50	Room to 100	212	>1.3	>50	>1.3	>50	>1.3	>50	...
	0–50	Boiling		>1.3	>50	>1.3	>50	>1.3	>50	...
Ferric sulfate	10	0–100	32–212	<0.05	<2	...	...	...	...	...
Formaldehyde	6–37	Boiling		<0.025	<1	...	...	<0.025	<1	...
	0–70	Room to 100	212	<0.05	<2	...	...	...	...	...
Fluoboric acid	5–20	Elevated		>1.3	>50	...	...	...	...	...
Fluosilicic acid	10	Room		>1.3	>50	...	...	...	...	...
Formic acid	10–90	35	95 to boiling	<0.13	<5	...	...	...	...	...
Formic acid (aerated)	10–90	Room to 100	212	<0.13	<5	...	...	...	...	...
Hydrazine	Mixture	109	230	<0.025	<1	...	...	...	...	2% hydrazine + saturated NaCl + 6% NaOH
	Mixture	130	265	nil		...	...	...	...	2% hydrazine + saturated NaCl + 6% NaOH
Hydrobromic acid	48	Boiling		<0.13	<5	...	...	<0.13	<5	B.P. = 125 °C (257 °F); shallow pits
	Mixture	Boiling		<0.025	<1	...	...	<0.025	<1	24% HBr + 50% acetic acid (glacial)
Hydrochloric acid	2	225	435	<0.025	<1	...	...	<0.025	<1	...
	5	Room		<0.025	<1	...	...	...	...	...
	10	35	95	<0.025	<1	...	...	...	...	...
	20	35	95	<0.025	<1	...	...	...	...	...
	32	30	85	<0.025	<1	...	...	...	...	...
	32	82	180	<0.025	<1	...	...	...	...	...
20% HCl + Cl_2 gas		58	135	0.13–0.25	5–10	...	...	...	...	Pitting
37% HCl + Cl_2 gas		58	135	<0.13	<5	...	...	...	...	...
10% HCl + 100 ppm $FeCl_3$		30	85	<0.025	<1	<0.05	<2	<0.025	<1	SCC observed
10% HCl + 100 ppm $FeCl_3$		105	220	<0.13	<5	...	...	...	...	Pitting rate
20% HCl + 100 ppm $FeCl_3$		105	220	<0.13	<5	...	...	...	...	...
37% HCl + 100 ppm $FeCl_3$		53	125	0.13–0.25	5–10	...	...	...	...	SCC observed
Hydrochloric acid	Mixture	Room		Dissolved		...	...	...	...	20% HCl + 20% HNO_3
	Mixture	Room		Dissolved		...	...	...	...	10% HCl + 10% HNO_3
Hydrofluoric acid	0–100	Room		>1.3	>50	...	...	...	...	...
Hydrogen peroxide	50	100	212	<0.05	<2	...	...	...	...	...
Hydroxyacetic acid		40	104	<0.13	<5	...	...	...	...	...
Lactic acid	10–100	148	298	<0.025	<1	...	...	...	...	...
	10–85	35	95 to boiling	<0.025	<1	...	...	...	...	...
Magnesium chloride	5–40	Room to 100	212	<0.05	<2	...	...	...	...	...
	47	Boiling		nil		...	...	nil		...
Manganese chloride	5, 20	Room to 100	212	<0.025	<1	...	...	...	...	...
Mercuric chloride	1-saturated	35–100	95–212	<0.025	<1	...	...	...	...	...
	Saturated	Boiling		<0.025	<1	...	...	<0.025	<1	...

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Table 12 (continued)

Medium	Concentration, %	Temperature °C	Temperature °F	Corrosion rate Zr702 mm/yr	Zr702 mils/yr	Zr704 mm/yr	Zr704 mils/yr	Zr705 mm/yr	Zr705 mils/yr	Remarks
Nickel chloride	5, 20	35–100	95–212	<0.025	<1	...	...	...	...	...
	5–20	100	212	<0.025	<1	...	...	...	...	...
	30	Boiling		nil		...	...	nil		...
Nitric acid	20	103	215	<0.025	<1	<0.025	<1	<0.025	<1	...
	70	121	250	<0.025	<1	<0.025	<1	<0.025	<1	...
	10–70	Room to 260	500	<0.025	<1	...	...	...	...	...
	70–98	Room-boiling		<0.025	<1	...	...	...	...	SCC observed
Nitric acid + 1% Fe	65	120	248	<0.025	<1	...	...	...	...	...
Nitric acid + 1% Fe	65	204	400	<0.025	<1	...	...	...	...	...
Nitric acid + 1.45% 304 stainless steel	65	204	400	nil		...	...	...	...	...
Nitric acid + 1% Cl^-	70	120	248	nil		...	...	...	...	...
Nitric acid + 1% seawater	70	120	248	nil		...	...	...	...	...
Nitric acid + 1% $FeCl_3$	70	120	248	nil		...	...	...	...	...
Oxalic acid	0–100	100	212	<0.025	<1	...	...	...	...	...
Perchloric acid	70	100	212	<0.05	<2	...	...	...	...	...
Sodium sulfate	0–20	Room to 100	212	<0.05	<2	...	...	...	...	...
Sodium sulfide	33	Boiling		nil		...	...	nil		...
Stannic chloride	5	100	212	<0.025	<1	...	...	...	...	...
	24	Boiling		<0.025	<1	...	...	...	...	...
Succinic acid	0–50	100	212	<0.05	<2	...	...	...	...	...
	100	150	300	<0.05	<2	...	...	...	...	...
Sulfuric acid	0–75	20	70	<0.025	<1	<0.025	<1	<0.025	<1	...
	80	20	70	<0.13	<5	>1.3	>50	...	...	...
	80	30	85	0.5–1.3	20–50	>1.3	>50	>1.3	>50	...
	77.5	60	140	0.25–0.5	10–20	...	...	<0.25	<10	...
	75	50	120	<0.025	<1	...	...	...	...	...
	77	50	120	0.13–0.25	5–10	>1.3	>50	...	...	...
	80	50	120	>1.3	>50	>1.3	>50	>1.3	>50	...
	75	80	125	<0.13	<5	...	...	<0.13	<5	...
	65	100	212	...	...	<0.025	<1	<0.13	<5	...
	70	100	212	<0.05	<2	...	...	<0.13	<5	...
	75	100	212	<0.13	<5	...	...	<0.13	<5	...
	76	100	212	<0.25	<10	...	...	...	...	...
	77	100	212	<0.5	<20	...	...	...	...	...
	77.5	100	212	>1.3	>50	>1.3	>50	>1.3	>50	...
	60	130	265	...	...	...	...	<0.13	<5	...
	65	130	265	<0.025	<1	...	...	...	...	...
	70	140	285	<0.13	<5	...	...	<0.25	<10	...
	58	Boiling		...	...	<0.025	<1	<0.13	<5	B.P. = 140 °C (284 °F)
	62	Boiling		<0.13	<5	...	...	0.5–1.3	10–20	B.P. = 146 °C (295 °F)
	64	Boiling		<0.13	<5	...	...	0.5–1.3	20–50	B.P. = 152 °C (306 °F)
	68	Boiling		<0.13	<5	...	...	...	...	B.P. = 165 °C (329 °F)
	69	Boiling		<0.13	<5	...	...	...	...	B.P. = 167 °C (333 °F)
	71	Boiling		<0.13	<5	...	...	...	...	B.P. = 171 °C (340 °F)
	72–74	Boiling		0.13–0.25	5–10	>1.3	>50	...	...	...
	75	Boiling		0.25–0.5	10–20	>1.3	>50	...	...	B.P. = 189 °C (372 °F)
Sulfuric acid										
+ 1000 ppm Fe^{3+}	60	Boiling		<0.025	<1	...	...	...	...	B.P. = 138–142 °C (280–288 °F)
+ 10 000 ppm Fe^{3+}	60	Boiling		<0.13	<5	...	...	...	...	Added as $Fe_2(SO_4)_3$
Sulfuric acid										
+200–1000 ppm Fe^{3+}	65	Boiling		<0.13	<5	...	...	...	...	B.P. = 152–155 °C (306–311 °F)
+10 000 ppm Fe^{3+}	65	Boiling		0.13–0.25	5–10	...	...	...	...	Added as $Fe_2(SO_4)_3$
Sulfuric acid										
+14 ppm–141 ppm Fe^{3+}	70	Boiling		0.13–0.25	5–10	...	...	...	...	B.P. = 167–171 °C (333–340 °F)
+200 ppm Fe^{3+}	70	Boiling		0.25–0.5	10–20	...	...	...	...	Added as $Fe_2(SO_4)_3$
+1410 ppm–10 000 ppm Fe^{3+}	70	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid										
+1000 ppm $FeCl_3$	60	Boiling		<0.13	<5	<0.13	<5	<0.5	<20	B.P. = 138–142 °C (280–288 °F)
+10 000 ppm $FeCl_3$	60	Boiling		<0.13	<5	<0.5	<20	0.5–1.3	20–50	...
+20 000 ppm $FeCl_3$	60	Boiling		0.5–1.3	20–50	0.5–1.3	20–50	>1.3	>50	...
Sulfuric acid										
+200 ppm $FeCl_3$	65	Boiling		<0.13	<5	<0.13	<5	<0.5	<20	B.P. = 152–155 °C (306–311 °F)
+1000 ppm $FeCl_3$	65	Boiling		<0.13	<5	<0.13	<5	<0.5	<20	...
+10 000 ppm $FeCl_3$	65	Boiling		<0.13	<5	<0.13	<5	<0.5	<20	...
Sulfuric acid										
+10 ppm $FeCl_3$	70	Boiling		<0.5	<20	<0.5	<20	>1.3	>50	B.P. = 167–171 °C (333–340 °F)
+100 ppm $FeCl_3$	70	Boiling		<0.5	<20	<0.5	<20	>1.3	>50	...
+200 ppm $FeCl_3$	70	Boiling		<0.5	<20	<0.5	<20	>1.3	>50	...
+1000 ppm $FeCl_3$	70	Boiling		<0.5	<20	<0.5	<20	>1.3	>50	...
+10 000 ppm $FeCl_3$	70	Boiling		0.5–1.3	20–50	>1.3	>50	>1.3	>50	...
Sulfuric acid										
+200 ppm Cu^{2+}	60	Boiling		<0.13	<5	...	...	...	...	Added as $CuSO_4$
+1000–10 000 ppm Cu^{2+}	60	Boiling		<0.025	<1	...	...	...	...	...

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Table 12 (continued)

Medium	Concentration, %	Temperature °C	°F	Corrosion rate Zr702 mm/yr	Zr702 mils/yr	Zr704 mm/yr	Zr704 mils/yr	Zr705 mm/yr	Zr705 mils/yr	Remarks
Sulfuric acid										
+200–10 000 ppm Cu^{2+}	65	Boiling		<0.13	<5	...	...	...	...	Added as $CuSO_4$
Sulfuric acid										
+3 ppm Cu^{2+}	70	Boiling		0.13–0.25	5–10	...	...	...	...	Added as $CuSO_4$
+27–226 ppm Cu^{2+}	70	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid										
+1000–10 000 ppm NO_3^-	60	Boiling		<0.13	<5	...	...	...	...	Added as $NaNO_3$
+50 000 ppm NO_3^-	60	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid										
+200–1000 ppm NO_3^-	65	Boiling		<0.13	<5	...	...	...	...	Added as $NaNO_3$
+10 000 ppm NO_3^-	65	Boiling		0.25–0.5	10–20	...	...	...	...	...
+50 000 ppm NO_3^-	65	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid										
+200 ppm NO_3^-	70	Boiling		0.13–0.25	5–10	...	...	...	...	Added as $NaNO_3$
+6000 ppm NO_3^-	70	Boiling		0.5–1.3	20–50	...	...	...	...	...
Sulfuric acid										
+1000 ppm NO_3^-	60	Boiling		<0.13	<5	...	...	...	...	Added as HNO_3
+10 000 ppm NO_3^-	60	Boiling		0.25–0.5	10–20	...	...	...	...	...
+50 000 ppm NO_3^-	60	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid										
+1000 ppm NO_3^-	65	Boiling		<0.13	<5	...	...	...	...	Added as HNO_3
+10 000–50 000 ppm NO_3^-	65	Boiling		>1.3	>50	...	...	...	...	...
Sulfuric acid	Mixture	Room to 100	212	<0.025	<1	...	...	...	...	1% H_2SO_4, 99% HNO_3
	Mixture	Room to 100	212	nil		...	...	...	...	10% H_2SO_4, 90% HNO_3
	Mixture	Boiling		<0.025	<1	...	...	...	...	14% H_2SO_4, 14% HNO_3
	Mixture	100	212	>1.3	>50	>1.3	>50	>1.3	>50	25% H_2SO_4, 75% HNO_3
	Mixture	Room		<0.025	<1	...	...	...	...	50% H_2SO_4, 50% HNO_3
	Mixture	Boiling		>1.3	>50	>1.3	>50	>1.3	>50	68% H_2SO_4, 5% HNO_3
	Mixture	Boiling to 135	275	0.25–0.5	10–20	0.25–0.5	10–20	>1.3	>50	68% H_2SO_4, 1% HNO_3
	Mixture	Room		>1.3	>50	>1.3	>50	>1.3	>50	75% H_2SO_4, 25% HNO_3
	Mixture	Boiling		<0.025	<1	...	...	...	...	7.5% H_2SO_4, 19% HCl
	Mixture	Boiling		<0.025	<1	...	...	...	...	34% H_2SO_4, 17% HCl
	Mixture	Boiling		<0.025	<1	...	...	...	...	40% H_2SO_4, 14% HCl
	Mixture	Boiling		0.025–0.13	1–5	...	...	...	...	56% H_2SO_4, 10% HCl
	Mixture	Boiling		<0.025	<1	...	...	...	...	60% H_2SO_4, 1.5% HCl
	Mixture	Boiling		<0.13	<5	...	...	...	...	69% H_2SO_4, 1.5% HCl
	Mixture	Boiling		0.25–0.5	10–20	...	...	...	...	69% H_2SO_4, 4% HCl
	Mixture	Boiling		<0.5	<20	...	...	...	...	72% H_2SO_4, 1.5% HCl
	Mixture	Boiling		>1.3	>50	...	...	>1.3	>50	20% H_2SO_4, 7% HCl with 50 ppm F^- impurities
Sulfurous acid	6	Room		<0.13	<5	...	...	...	...	...
	Saturated	192	380	0.13–1.3	5–50	...	...	...	...	...
Sulfamic acid	10	Boiling		nil		...	...	nil		B.P. = 101 °C (214 °F)
Tannic acid	25	35–100	95–212	<0.025	<1	...	...	...	...	...
Tartaric acid	10–50	35–100	95–212	<0.025	<1	...	...	...	...	...
Trichloroacetic acid	10–40	Room		<0.05	<2	...	...	...	...	...
	100	Boiling		>1.3	>50	...	...	...	...	...
	100	100	212	>1.3	>50	...	...	...	...	B.P. = 195 °C (383 °F)
Tetrachloroethane	100	Boiling		<0.13	<5	...	...	...	...	B.P. = 146 °C (295 °F) symmetrical B.P. = 129 °C (264 °F) unsymmetrical
Trichloroethylene	99	Boiling		<0.13	<5	...	...	...	...	B.P. = 87 °C (189 °F)
Trisodium phosphate	5–20	100	212	<0.13	<5	...	...	...	...	...
Urea reactor mixture	Mixture	193	380	0.025	<1	...	...	...	...	58% urea, 17% NH_3, 15% CO_2, 10% H_2O
Zinc chloride	70	Boiling		nil		...	...	nil		...
	5–20	35	95 to boiling	<0.025	<1	...	...	...	...	...
	40	180	355	<0.025	<1	...	...	<0.025	<1	...

Tantalum and Tantalum Alloys

Tantalum is an exceptionally versatile corrosion-resistant metal. It combines the inertness of glass with the strength and ductility of low-carbon steel. Although expensive, recent fabrication techniques, in which thin linings of tantalum are used in chemical-processing equipment, have resulted in equipment that has the acid corrosion resistance provided by tantalum but at a much lower cost than an all-tantalum construction. In other cases, the long life and reliability of

tantalum equipment in severe corrosion applications often more than offsets the higher initial cost. Table 13 gives the effects of acids on tantalum, Table 14 the effects of salts; and Table 15 the effects of miscellaneous corrosive reagents.

The outstanding corrosion resistance and inertness result from a very thin, impervious, protective oxide film that forms upon exposure of the metal to slightly anodic or oxidizing conditions. Although tantalum pentoxide (Ta_2O_5) is the usual oxide form, suboxides may also exist in transition between the base metal and the outer film. It is only when these oxide films react with, or are penetrated by, a chemical reagent that attack occurs on the underlying metal substrate.

The oxide film adheres well, and it appears to be free from porosity. There have, however, been some reports concerning the suboxides, which are stable up to 425 °C (800 °F). When tantalum is heated above this level, only the stable pentoxide exists. Thus, internal stress set up by the metal during oxide conversion causes the protective oxide film to flake and spall.

Tantalum occupies a position toward the electropositive end of the electromotive force (emf) series, and thus it tends to become cathodic in the galvanic cell circuit formed by contact with almost all other metals. Because of this cathodic behavior, atomic hydrogen, which may be liberated, can be absorbed by the tantalum and result in hydrogen embrittlement. Stray voltages can also cause this undesired effect. Therefore, when used in chemical-processing equipment, tantalum must be protected from becoming cathodic so that the material will not become embrittled.

Because of the wide ranges of type, concentration, and temperature of the media to which it exhibits excellent corrosion resistance, tantalum has found primary application in the chemical-processing industry.

Water

Tantalum is not attacked by fresh water, mine waters (which are usually acidic), or seawater, either cold or hot. It shows no sign of corrosion in deionized water at 40 °C (100 °F). For tantalum equipment exposed to boiler waters and condensates, the alkalinity must be controlled. The pH should be less than 9 and preferably no more than 8. No failures caused by exposure of tantalum to steam condensate have ever been recorded. Tantalum is used in many cases at saturated steam pressures above 1035 kPa (150 psi) at temperatures of 185 °C (365 °F) and is considered resistant to saturated steam below 250 °C (480 °F) at a pressure of 3.9 MPa (560 psi).

Acids

The chemical properties of tantalum are similar to those of glass. Thus, tantalum is immune to attack by almost all acids except HF. Tantalum is *not* attacked by such agents as sulfuric acid (H_2SO_4), nitric acid (HNO_3), hydrochloric acid (HCl), aqua regia, perchloric acid ($HClO_4$), chlorine, bromide, hydrobromic acid (HBr), or any of the bromides, phosphoric acid (H_3PO_4) when free of the F^- ion, nitric oxides, chlorine oxides, hypochlorous acid (HClO), organic acids, and hydrogen peroxide (H_2O_2) at ordinary temperatures. Tantalum is attacked, even at room temperature, by strong alkalis, HF, and free sulfur trioxide (SO_3), as in fuming H_2SO_4.

Salts

Tantalum is not attacked by dry salts or by salt solutions at any concentration or temperature unless HF is liberated when the salt dissolves or unless a strong alkali is present. Salts that form acidic solutions have no effect on tantalum. However, fused sodium hydrosulfate ($NaHSO_4$) or $KHSO_4$ dissolves tantalum.

Alkalis

Sodium hydroxide (NaOH) and potassium hydroxide (KOH) solutions do not dissolve tantalum, but they do tend to destroy the metal by formation of successive layers of surface scale. The rate of the destruction increases with concentration and temperature. Damage to tantalum equipment has been experienced unexpectedly when strong alkaline solutions are used during cleaning and maintenance.

Tantalum *is* attacked, even at room temperature, by concentrated alkaline solutions. It is dissolved by molten alkalis. However, tantalum is fairly resistant to dilute alkaline solutions. In a long-term exposure test in a paper mill, tantalum suffered no attack in a solution with a pH of 10.

Organic Compounds

In general, tantalum is completely resistant to organic compounds. It is used in heat exchangers, spargers, and reaction vessels in several important organic reactions, particularly when corrosive inorganics are involved.

Most organic salts, gases, alcohols, ketones, alkaloids, and esters have no effect on tantalum. Specific exceptions, however, should be made for reagents that may hydrolyze to HF or contain free SO_3 or strong alkalis.

Gases

Tantalum and all of its known alloys react with hydrogen, nitrogen, and oxygen at temperatures above 300 °C (570 °F). Hydrogen is dissolved in the pure metal above 350 °C (660 °F); it is evolved at higher temperatures. Little hydrogen remains at 800 °C (1470 °F). An oxide film may inhibit the reaction until higher temperatures are reached.

Nitrides among other phases form at the surface, but at higher temperatures these decompose. At 2100 °C (3800 °F), all the nitrogen is liberated.

Of these reactions, the most important is the reaction with oxygen. Tantalum tends to form oxides when heated in air. Reaction starts above 300 °C (570 °F). It becomes rapid above 600 °C (1100 °F). The scale is not adherent at this point. If the oxidized material is heated above 1000 °C (1830 °F), oxygen diffuses into the material and embrittles it.

Tantalum is attacked by carbon dioxide at 500 °C (930 °F). It is attacked by carbon monoxide above 1100 °C (2000 °F). In either instance, oxide is formed; at higher temperatures, tantalum carbide is also formed.

Table 13 Effects of Acids on Tantalum

Acid	Concentration, %	Temperature, °C (°F)	Code(a)
Acetic acid	5–99.5	Room to boiling	E
Acetic acid, glacial	99.7	Room to boiling	E
Acetic acid vapor	0–100	Room to boiling	E
Acetic anhydride	99	Room	E
Aqua regia	3 HCl, 1 HNO_3	Room to 77 (170)	E
Arsenic acid	90	Room	E
Benzoic acid	5	Room	E
	Saturated	Room	E
Boric acid	5	Room to boiling	E
	10	Room to boiling	E
	Saturated	Room	E
Butyric acid	5	Room	E
Carbolic acid	Saturated	Room	E
	...	...	E
Chloroacetic acid	30	Room to 82 (180)	E
	100	Room to boiling	E
Chloric acid	...	Room	E
Chlorosulfonic acid	10	...	E
Chromic acid	5–50	Room to boiling	E
Citric acid	5	Room	E
	10–25	Room to boiling	E
Citric acid (nonaerated)	50	Room to 100 (212)	E
Citric acid (aerated)	50	Room to 100 (212)	E
Citric acid	Concentrated	Room to boiling	E
Dichloroacetic acid	100	Room to 100 (212)	E
	100	Room to boiling	E
Fatty acids	...	...	E
Fluoboric acid	5–20	Elevated	NR
Fluorosilicic acid	10	Room	NR
Formic acid (still)	5	Room to 66 (150)	E
Formic acid (nonaerated)	10–50	Room to boiling	E
Formic acid (aerated)	10–90	Room to 100 (212)	E
Gallic acid	5	Room to boiling	E
Hydrobromic acid	0–100	Room to boiling	E
Hydrochloric acid (nonaerated)	5–20	Room to 35 (95)	E
Hydrochloric acid (aerated)	5–20	Room to 35 (95)	E
Hydrochloric acid	All	Room to 71 (160)	E
Hydrochloric acid fumes	Concentrated	Room to 38 (100)	E
Hydrocyanic acid	...	...	E
Hydrofluoric acid	5–48	Room	NR
Hydrofluoric acid (anhydrous)	100	Room	NR
Hydrofluoric acid vapors	...	Room	NR
Hydrofluoric-nitric acid	1 HF:15 HNO_3	Room	NR
Hydrofluosilicic acid	5	Room	V
Hydrofluosilicic acid vapors	...	100 (212)	NR
Hydroxyacetic acid	...	Room to 40 (105)	E
Lactic acid	5	Room to 66 (150)	E
	10–100	Room to boiling	E
Malic acid	...	Room and hot	E
Methyl-sulfuric acid	0–100	Room to 150 (300)	E
Molybdic acid	5	Room	E
Muriatic acid	...	Room	E
Nitric acid	5	Room	E
	10–40	Room to 100 (212)	E
	50–65	Room to boiling	E
	69.5	Room to 100 (212)	E
Nitric acid (white fuming)	90	Room to 82 (180)	E
Nitric acid	95	Room	E
Nitric acid	Concentrated	Room to boiling	E
Nitric acid	Fuming	Room	E
Nitrous acid	5	Room	E
Oleic acid	...	Room	E
Oxalic acid	1	Room to 38 (100)	E
	5	Room to 35 (95)	E
	10	Room to boiling	E
	0.5–25	Room to 60 (140)	E
	Saturated	Room to 93 (200)	E
Perchloric acid	0–100	Room to 150 (300)	E
Phenol (carbolic acid)	Saturated	Room	E
Phosphoric acid	1	Room	E
Phosphoric acid	5	Room to 100 (212)	E
Phosphoric acid (still)	10	Room to 175 (350)	E
Phosphoric acid (agitated)	10	Room	E
Phosphoric acid (aerated)	10	Room	E
Phosphoric acid	5–30	Room	E
Phosphoric acid	35–85	Room	E
Phosphoric acid	85	Room to 38 (100)	E
Phosphoric-sulfuric + $CuSO_4$	$15H_3PO_4$-$10H_2SO_4$	Room to 66 (150)	E
Picric acid	Concentrated	...	E
Propionic acid vapor	...	190 (375)	E
Pyrogallic acid	...	...	E
Salicylic acid	...	Room	E
Stearic acid	Concentrated	Room to 93 (200)	E
Succinic acid	...	Molten	E
Sulfuric acid	1–5	Room to 60 (140)	E
	5	Room to 60 (140)	E
	10	Room to boiling	E
	15	Room	E
	50	Room to boiling	E
	Concentrated	Room to 150 (300)	E
	Concentrated	Boiling	NR
	Fuming	Room	NR
Sulfuric acid vapors	96	Room to 150 (300)	E
Sulfuric anhydride	Dry	Room	NR
Sulfuric-nitric acid	90–10	Room	E
	70–30	Room	E
	50–50	Room to 60 (140)	E
	30–70	Room	E
	10–90	Room to 60 (140)	E
Sulfurous acid	6	Room	E
	Saturated	Room to 190 (375)	E
Sulfurous spray	...	Room	E
Tannic acid	10	Room to 66 (150)	E
	25	Room to 100 (212)	E
Tartaric acid	10	Room to 100 (212)	E
	25	Room to 100 (212)	E
	50	Room to 100 (212)	E

(a) E, no attack; V, variable depending on temperature and concentration; NR, not resistant

Table 14 Effects of Salts on Tantalum

Salt	Concentration, %	Temperature, °C (°F)	Code(a)
Aluminum acetate	Saturated	Room	E
Aluminum chloride	5	Room	E
Aluminum chloride (aerated)	5–10	Room to 60 (140)	E
Aluminum chloride	25	Room to 100 (212)	E
Aluminum fluoride	5	Room	NR
	Saturated	Room	NR
Aluminum hydroxide	Saturated	...	E
Aluminum potassium sulfate (alum)	2	Room	E
	10	Room to boiling	E
Aluminum sulfate	10–saturated	Room to boiling	E
Ammonium acid phosphate	10	Room	E
Ammonium alum	...	...	E
Ammonium alum (slightly ammoniacal)	...	...	E
Ammonium bicarbonate	50	Room to 100 (212)	E
Ammonium bromide	5	Room	E
Ammonium carbonate	50	Room to 100 (212)	E
Ammonium carbonate (aqueous)	50	Room to boiling	E
Ammonium carbonate	All	Room to hot	E
Ammonium chloride	1	Room	E
	10–50	Room to boiling	E
Ammonium fluoride	10	Room	NR
Ammonium hydroxide	...	...	V
Ammonium monosulfate	...	...	E
Ammonium nitrate	0–100	Room to 150 (300)	E
Ammonium oxalate	5	Room	E
Ammonium persulfate	5	Room	E
Ammonium phosphate	5	Room	E
Ammonium sulfate (aerated)	1	Room	E
	5	Room to 100 (212)	E
Ammonium sulfate	10	Room to 100 (212)	E
Ammonium sulfate	Saturated	Room to boiling	E
Ammonium sulfite	Saturated	Room to boiling	E
Amyl acetate	...	...	E
Aniline hydrochloride	5	Room	E
	20	Room to 38 (100)	E
Antimony trichloride	...	Room	E
Barium carbonate	Saturated	Room	E
Barium chloride	5 to saturated	Room	E
	5	Room to 100 (212)	E
	20	Room to 100 (212)	E
	25	Room to boiling	E
Barium hydroxide	Saturated	...	EE
Barium hydroxide·$8H_2O$	Saturated	Room	E
Barium nitrate	Aqueous solution	Room to hot	E
Barium sulfate	...	Room	E
Butyl acetate	...	Room	E
Calcium bisulfite	...	Room	E
Calcium carbonate	Saturated	Room to boiling	E
Calcium chlorate	Dilute	Room to hot	E
Calcium chloride	5–20	Room to 100 (212)	E
	28	Room to boiling	E
	Concentrated	Room	E
Calcium hydroxide	10–saturated	Room to boiling	E
Calcium hypochlorite	2–saturated	Room to boiling	E
Calcium sulfate	Saturated	Room	E
Copper acetate	Saturated	Room	E
Copper carbonate	Saturated	...	E
Copper chloride (agitated, aerated)	1	Room	E
Copper chloride (agitated)	5	Room	E
Copper chloride (aerated)	5	Room	E
Copper cyanide (electroplating solution)	...	Room	E
Copper cyanide	Saturated	Room to boiling	E
Copper nitrate	1–saturated	Room	E
Copper sulfate	5	Room	E
	Saturated	Room to boiling	E
Cupric carbonate-cupric hydroxide	Saturated	Room	E
Cupric chloride	20–50	Room to boiling	E
Cupric cyanide	Saturated	Room	E
Cupric nitrate	...	Room to 40 (105)	E
Cuprous chloride	50	Room to 90 (195)	E
Ferric chloride (still)	1–50	Room to boiling	E
Ferric chloride (agitated)	5	Room	E
Ferric chloride (aerated)	5	Room	E
Ferric hydroxide	...	Room	E
Ferric nitrate	1–5	Room	E
Ferric sulfate	1–saturated	Room	E
Ferrous chloride	...	Room	E
Ferrous sulfate	Dilute	Room	E
Ferrous ammonium citrate	...	...	E
Fluoride salts	Variable	Variable	V
Hydrogen bromide	...	...	E
Hydrogen peroxide	3–30	Room	E
	...	Room to boiling	E
Hydrogen iodide	...	...	E
Hydrogen sulfide	Dry	Room	E
	Saturated H_2O	Room	E
Hyposulfite soda (hypo)	...	...	E
Lactic acid salts	...	Room	E
Lead acetate	Saturated	Room	E
Magnesium carbonate	...	...	E
Magnesium chloride (still)	1–5	Room to hot	E
Magnesium chloride	5–40	Room to boiling	E
Magnesium hydroxide	Saturated	Room	E
	Thick suspension	Room	E
Magnesium nitrate	...	...	E
Magnesium sulfate	5	Room to hot	E
	Saturated	Room	E
Manganese carbonate	...	...	E
Manganese chloride	10–50 (Aqueous)	Room to boiling	E
Manganous chloride	5–20	Room to 100 (212)	E
Mercuric bichloride	0.07	Room	E
Mercuric chloride	1–saturated	Room to 100 (212)	E
Mercuric cyanide	Saturated	...	E
Mercurous nitrate	...	...	E
Nickel chloride	5–20	Room to 100 (212)	E
Nickel nitrate	10	Room	E
Nickel nitrate plus 6% H_2O	50	Room	E
Nickel sulfate	10	Room	E
Phosphoric anhydride	Dry	Room	E
Phosphorus trichloride		...	...
	Saturated	Room	E
Phthalic anhydride	...	...	E
Potassium bichromatic (neutral)	...	Room	E
Potassium bromide	5–saturated	Room	E
Potassium carbonate	1	Room	E
Potassium chlorate	...	...	E
Potassium chloride	1–36	Room to boiling	E
	Saturated	Room	E
Potassium cyanide	...	...	E
Potassium dichromate (neutral)	...	...	E
Potassium ferricyanide	5–saturated	Room	E
Potassium ferricyanide plus 5% NaCl	0.5	Room	E
Potassium ferrocyanide	5	Room	E
Potassium hydrate	...	...	E
Potassium hydroxide	5	Room	E
	27–50	Boiling	NR
Potassium iodide	Saturated	Room	E
Potassium iodide—iodine	...	...	E
Potassium iodide plus 0.1% Na_2CO_3	Saturated	Room	E
Potassium nitrate	5	Room	E
Potassium oxalate	...	...	E
Potassium permanganate (neutral)	...	...	E
Potassium pyrosulfate	...	Molten	NR
Potassium sulfate	1–5	Room to hot	E
	10	Room	E
Potassium sulfide	...	...	E
Potassium thiosulfate	1	Room	E
Silver bromide	...	...	E

(a) E, no attack; V, variable, depending on temperature and concentration; NR, not resistant

(Continued)

Table 14 (continued)

Salt	Concentration, %	Temperature, °C (°F)	Code(a)
Silver chloride	...	...	E
Silver cyanide	...	...	E
Silver nitrate	50	Room	E
Sodium acetate (moist)	5	Room	E
Sodium acetate	Saturated	Room	E
Sodium aluminate	25	Room to boiling	E
Sodium benzoate	...	...	E
Sodium bicarbonate	All	Room to 66 (150)	E
Sodium bichromate (neutral)	...	...	E
Sodium bisulfate	Solution	...	E
	10–25	Room to boiling	E
	Saturated	Room	E
	...	Molten	NR
Sodium borate	...	...	E
Sodium bromide	5	Room	E
Sodium carbonate	10–25	Room to boiling	E
	All	Room	E
Sodium chlorate	10–25	Room	E
	Saturated	Room	E
Sodium chloride (still)	5	Room to 40 (105)	E
Sodium chloride (aerated)	20	Room	E
Sodium chloride	29	Room to boiling	E
	Saturated	Room to boiling	E
Sodium citrate	Saturated	Room	E
Sodium cyanide	Saturated	Room	E
Sodium dichromate	Saturated	Room	E
Sodium ferricyanide	...	...	E
Sodium ferrocyanide	...	...	E
Sodium fluoride	5–saturated	Room	NR
Sodium hydrosulfite	...	...	E
Sodium hydroxide	10–saturated	Room	NR
	10	Boiling	NR
	25	Room to boiling	NR
	40	80 (175)	NR
Sodium hypochlorite	6	Room	E
Sodium hyposulfite	Dilute	Room	E
Sodium lactate	...	...	E
Sodium nitrate	All	Room	E
Sodium nitrite	...	...	E
	Saturated	Room	E
Sodium peroxide	...	100 (212)	V
Sodium phosphate	5–saturated	Room	E
Sodium pyrosulfate	...	Molten	NR
Sodium silicate	...	...	E
	25	Room to boiling	E
Sodium sulfate (still)	5	Room	E
Sodium sulfate	10–20	Room to boiling	E
Sodium sulfate	Saturated	Room	E
Sodium sulfide	10	Room to boiling	E
	Saturated	Room	E
Sodium sulfite	5	Room	E
	10–saturated	Room to boiling	E
Sodium thiosulfate	10–25	Room to boiling	E
Sodium thiosulfate—acetic acid	20	Room	E
Stannic chloride	5	Room to 100 (212)	E
	24	Room to boiling	E
	100	Molten	E
Stannous chloride	5–saturated	Room	E
Sulfur chloride	Dry	...	E
Sulfuryl chloride	...	...	E
Thionyl chloride	...	...	E
Tin salts	...	...	E
Titanium tetrachloride	...	...	E
Zinc chloride (still)	5	Room to boiling	E
Zinc chloride	10	Room to boiling	E
	20	Room to 100 (212)	E
	Saturated	Room	E
Zinc sulfate	5–saturated	Room	E
	25	Room to boiling	E

(a) E, no attack; V, variable, depending on temperature and concentration; NR, not resistant

Table 15 Effects of Miscellaneous Corrosive Reagents on Tantalum

Medium	Concentration, %	Temperature, °C (°F)	Code(a)
Acetone	...	Boiling	E
Air	...	Below 300 (570)	E
	...	Above 300 (570)	NR
Amines	...	...	E
Aniline	Concentrated	Room	E
Baking oven gases	...	...	E
Beer	...	...	E
Benzene	...	Room	E
Benzol	...	Hot	E
Bleaching powder	Solution	Hot	V
Blood (meat juices)	...	Cold	E
Body fluids	...	...	E
Borax	...	Fused	NR
Bromine	Dry	Below 300 (570)	E
	Wet	...	E
Bromine water	...	Room	E
Buttermilk	...	Room	E
Carbon bisulfide	...	Room	E
Carbon tetrachloride	99	Boiling	E
	Liquid	Boiling	E
	Pure	Room	E
	5–10 aqueous solution	Room	E
Chlorinated brine	...	...	E
Chlorinated hydrocarbons	...	...	E
Chlorinated water	Saturated	Room	E
Chlorine dioxide	...	180 (355)	E
Chlorine gas	Dry	Up to 250 (480)	E
	Moist (1.5% H_2O)	Up to 375 (705)	E
	Moist (30% H_2O)	Up to 400 (750)	E
Chloroform	...	Room	E
Chromium plating bath	...	Room	E
Cider	...	Room	E
Coffee	...	Boiling	E
Copal varnish	...	...	E
Cream of tartar	...	...	E
Creosote (coal tar)	...	Hot	E
Crude oil	...	...	E
Developing solutions	...	Room	E
Distillery wort	...	...	E
Dyewood, liquor	...	Room	E
Ether	...	Room	E
Ethyl acetate	...	...	E
Ethyl chloride	5	Room	E
Ethyl sulfate	...	...	E
Ethylene chloride	...	Room	E
Ethylene dibromide	...	...	E
Ethylene dichloride	100	Boiling	E
Flue gases	...	...	E
Fluorine	...	Room	NR
Food pastes	...	...	E
Formaldehyde	...	Room	E
Formaldehyde plus 2.5% H_2SO_4	50	158 (315)	E
Fuel oil	...	Hot	E
Fuel oil (containing H_2SO_4)	...	Hot	E
Fruit juices	...	Room	E
Furfural	...	...	E

(a) E, no attack; V, variable, depending on temperature and concentration; NR, not resistant

(Continued)

Table 15 (continued)

Medium	Concentration, %	Temperature, °C (°F)	Code(a)
Gasoline	...	...	E
Glauber's salt	Solution	Hot	E
Glue, dry	...	Room	E
Glue, solution acid	...	Hot	E
Glycerine	...	Room	E
Gypsum	...	...	E
Hydrocarbons	...	...	E
Hydrogen	...	Up to 300 (570)	E
Ink	...	...	E
Iodine	...	Up to 300 (570)	E
Idoform	...	...	E
Kerosene	...	Room	E
Ketchup	...	Room	E
Lard	...	Room	E
Linseed oil	...	...	E
Lye (caustic)	34	110 (230)	NR
Lysol	...	100 (212)	E
Mayonnaise	...	Hot and cold	E
Meats (unsalted)	...	Room	E
Mash	...	Hot	E
Methylene chloride	40	Room to boiling	E
Milk	Fresh or sour	Hot or cold	E
Mine water, acid	...	...	E
Molasses	...	...	E
Mustard	...	Room	E
Naphtha	...	...	E
Nitre cake	...	Fused	NR
Nitric oxides	...	...	E
Nitrosyl chloride	...	...	E
Nitrous oxide	Dry	...	E
Oils, crude	...	Hot and cold	E
Oils, mineral, vegetable	...	Hot and cold	E
Organic chlorides	...	...	E
Oxygen	...	Up to 300 (570)	E
Paraffin	...	Molten	E
Paraffin	...	Molten	E
Paregoric compound	...	...	E
Petroleum ether	...	...	E
Phenol	...	...	E
Phenolic resins	...	...	E
Pine tar oil	...	...	E
Potash	Solution	Hot	NR
Quinine bisulfate (dry)	...	...	E
Quinine sulfate (dry)	...	...	E
Rosin	...	Molten	E
Sal ammoniac	20	Boiling	E
Salt	Saturated	Room	E
Salt brine	Saturated	Hot	E
Salt water	...	...	E
Sewage	...	...	E
Soaps	...	Room	E
Soy bean oil	...	...	E
Starch	Solution	...	E
Steam	...	...	E
Sugar juice	...	...	E
Sulfur, dry	...	Molten	E
Sulfur, wet	...	...	E
Sulfur dioxide	Dry	Room	E
	Moist	Room	E
Sulfur trioxide	Dry	Room	NR
Tomato juice	...	Room	E
Turpentine oil	...	...	E
Tung oil	...	...	E
Varnish	...	...	E
Vegetable juices	...	...	E
Vegetable oil	...	Hot and cold	E
Vinegar	Still	Room	E
	Agitated	Room	E
	Aerated	Room	E
	Fumes	...	E
Vinegar and salt	...	...	E
Water	...	...	E
	...	Hot	E
	Salt	...	E
	Sea	...	E
Whiskey	...	...	E

Niobium and Niobium Alloys

Niobium and niobium alloys are used principally in several corrosion-resistant applications. These involve rocket and jet engines, nuclear reactors, sodium vapor highway lighting equipment, and chemical-processing equipment. Niobium has many of the same properties as tantalum, its "sister" metal. One common property is the interaction with the reactive elements hydrogen, oxygen, nitrogen, and carbon at temperatures above 300 °C (570 °F). These reactions cause severe embrittlement. Consequently, at elevated temperatures, the metal must be protectively coated or used in vacuum or inert atmospheres.

Niobium resists a wide variety of corrosive environments, including concentrated mineral acids, organic acids, liquid metals (particularly sodium and lithium), metal vapors, and molten salts. Table 16 gives the corrosion rates of niobium in aqueous media.

Like other reactive metals, niobium derives its corrosion resistance from a readily formed, adherent, passive oxide film. Its corrosion properties are similar to those of tantalum, but niobium is less resistant in aggressive mediums such as hot, concentrated mineral acids.

Niobium is susceptible to hydrogen embrittlement if cathodically polarized by either galvanic coupling or by impressed potential. In addition to being very stable, the anodic niobium oxide film has a high dielectric constant and a high breakdown potential.

Acid Solutions

Niobium is resistant to most organic acids and mineral acids, except hydrofluoric acid (HF), at all concentrations and temperatures below 100 °C (212 °F). These acids include the halogen acids hydrochloric (HCl), hydroiodic (HI), and hydrobromic (HBr); nitric acid (HNO_3); sulfuric acid (H_2SO_4); and phosphoric acid (H_3PO_4). Niobium is especially resistant under oxidizing conditions. At room temperature, niobium is resistant to H_2SO_4 at all concentrations up to 95%. The corrosion rate increases rapidly with temperature and concentration.

Niobium is completely resistant to dilute sulfurous acid (H_2SO_3) at 100 °C (212 °F). In concentrated acid at the same temperature, it has a corrosion rate of 0.25 mm/yr (10 mils/yr). Niobium is completely resistant to HNO_3, having a corrosion rate of 0.025 mm/yr (1 mil/yr) in 70% HNO_3 at 250 °C (480 °F).

Niobium is inert in mixtures of HNO_3 and HCl. It has a corrosion rate of less than 0.025 mm/yr (1 mil/yr) in aqua regia at 55 °C (130 °F). In boiling 40 and 50% H_3PO_4 with small amounts of F- impurity (5 ppm), niobium has a corrosion rate of 0.25 mm/yr (10 mils/yr). In mixtures of $HNO_3$10 and H_2SO_4, niobium can dissolve readily.

Alkaline Solutions

In ambient aqueous alkaline solutions, niobium has corrosion rates of less than 0.025 mm/yr (1 mil/yr). At higher temperatures, even though the corrosion rate does not seem excessive, niobium is embrittled even at low concentrations (5%) of sodium hydroxide (NaOH) and potassium hydroxide (KOH). Like tantalum, niobium is embrittled in salts that hydrolyze to form alkaline solutions. These salts include sodium and potassium carbonates and phosphates.

Salt Solutions

Niobium has excellent corrosion resistance to salt solutions, except those that hydrolyze to form alkalis. It is resistant to chloride solutions even in the presence of oxidizing agents. It does not corrode in 10% ferric chloride ($FeCl_3$) at room temperature, and it is resistant to attack in seawater.

Gases

Niobium is easily oxidized. It will oxidize in air above 200 °C (390 °F). The reaction, however, does not become rapid until above red heat (about 500 °C, or 930 °F). At 980 °C (1795 °F), the oxidation rate is 430 mm/yr (17 in./yr). In pure oxygen, the attack is catastrophic at 390 °C (735 °F). Oxygen diffuses freely through the metal; this causes embrittlement.

Niobium reacts with nitrogen above 350 °C (660 °F), with water vapor above 300 °C (570 °F), with chlorine above 200 °C (390 °F), and with carbon dioxide, carbon monoxide, and hydrogen above 250 °C (480 °F).

At a temperature of 100 °C (212 °F), niobium is inert in most common gases, for example, bromine, chlorine, nitrogen, hydrogen, oxygen, carbon dioxide, argon monoxide, and sulfur dioxide (wet or dry).

Table 16 Corrosion of Niobium in Aqueous Media

Source: Teledyne Wah Chang Albany, Albany, OR, 1986

Medium	Concentration, %	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Mineral acids				
Hydrochloric acid	1	Boiling	nil	
Hydrochloric acid (aerated)	15	Room-60 (140)	nil	
Hydrochloric acid (aerated)	15	100 (212)	0.025	1.0
Hydrochloric acid (aerated)	30	35 (95)	0.025	1.0
Hydrochloric acid (aerated)	30	60 (140)	0.05	2.0
Hydrochloric acid (aerated)	30	100 (212)	0.125	5.0
Hydrochloric acid	37	Room	0.025	1.0
Hydrochloric acid	37	60 (140)	0.25	10
Hydrochloric acid	37% with Cl_2	60 (140)	0.5	20
Hydrochloric acid	10% with 0.1% $FeCl_3$	Boiling	0.025	1.0
Hydrochloric acid	10% with 0.6% $FeCl_3$	Boiling	0.125	5.0
Hydrochloric acid	10% with 35% $FeCl_2$ and 2% $FeCl_3$	Boiling	0.05	2.0
Nitric acid	65	Room	nil	
Nitric acid	70	250 (480)	0.025	1.0
Phosphoric acid	60	Boiling	0.5	20
Phosphoric acid	85	Room	0.0025	0.1
Phosphoric acid	85	88 (190)	0.05	2.0
Phosphoric acid	85	100 (212)	0.125	5.0
Phosphoric acid	85	Boiling	3.75	150
Phosphoric acid	85% with 4% HNO_3	88 (190)	0.025	1.0
Phosphoric acid	40–50% with 5 ppm F	Boiling	0.25	10
Sulfuric acid	5–40	Room	nil	
Sulfuric acid	98	Room	Embrittlement	
Sulfuric acid	10	Boiling	0.125	5.0
Sulfuric acid	25	Boiling	0.25	10
Sulfuric acid	40	Boiling	0.5	20
Sulfuric acid	40% with 2% $FeCl_3$	Boiling	0.25	10

(Continued)

Table 16 (continued)

Medium	Concentration, %	Temperature, °C (°F)	Corrosion rate mm/yr	mils/yr
Sulfuric acid	60	Boiling	1.25	50
Sulfuric acid	60% with 0.1–1% $FeCl_3$	Boiling	0.5	20
Sulfuric acid	20% with 7% HCl and 100 ppm F^-	Boiling	0.25	10
Sulfuric acid	50% with 20% HNO_3	50–80 (120–175)	nil	
Sulfuric acid	50% with 20% HNO_3	Boiling	0.25	10
Sulfuric acid	72% + 3% CrO_3	100 (212)	0.025	1.0
Sulfuric acid	72% + 3% CrO_3	125 (255)	0.125	5.0
Sulfuric acid	72% + 3% CrO_3	Boiling	3.75	150
Organic acids				
Acetic acid	5–99.7	Boiling	nil	
Citric acid	10	Boiling	0.025	1.0
Formaldehyde	37	Boiling	0.0025	0.1
Formic acid	10	Boiling	nil	
Lactic acid	10–85	Boiling	0.025	1.0
Oxalic acid	10	Boiling	1.25	50
Tartaric acid	20	Room-boiling	nil	
Trichloroacetic acid	50	Boiling	nil	
Trichloroethylene	99	Boiling	nil	
Alkalies				
NaOH	1–40	Room	0.125	5.0
NaOH	1–10	98 (208)	Embrittlement	
KOH	5–40	Room	Embrittlement	
KOH	1–5	98 (208)	Embrittlement	
NH_4OH	...	Room	nil	
Salts				
$AlCl_3$	25	Boiling	0.005	0.2
$Al_2(SO_4)_3$	25	Boiling	nil	
$AlK(SO_4)_2$	10	Boiling	nil	
$CaCl_2$	70	Boiling	nil	
$Cu(NO_3)_2$	40	Boiling	nil	
$FeCl_3$	10	Room-boiling	nil	
$HgCl_2$	Saturated	Boiling	0.0025	0.1
K_2CO_3	1–10	Room	0.025	1.0
K_2CO_3	10–20	98 (208)	Embrittlement	
K_3PO_4	10	Room	0.025	1.0
$MgCl_2$	47	Boiling	0.025	1.0
NaCl	Saturated; pH = 1	Boiling	0.025	1.0
Na_2CO_3	10	Room	0.025	1.0
Na_2CO_3	10	Boiling	0.5	20
Na_2HSO_4	40	Boiling	0.125	5.0
NaOCl	6	50 (120)	1.25	50
Na_3PO_4	5–10	Room	0.025	1.0
Na_3PO_4	2.5	98 (208)	Embrittlement	
NH_2SO_3H	10	Boiling	0.025	1.0
$NiCl_3$	30	Boiling	nil	
$ZnCl_2$	40–70	Boiling	nil	
Miscellaneous				
Bromine	Liquid	20 (70)	nil	
Bromine	Vapor	20 (70)	0.025	1.0
Chromium plating solution	25% CrO_3, 12% H_2SO_4, H_2O	92 (198)	0.125	5.0
Chromium plating solution	17% CrO_3, 2% Na_5SiF_6, trace H_2SO_4, H_2O	92 (198)	0.125	5.0
H_2O_2	30	Room	0.025	1.0
H_2O_2	30	Boiling	0.5	20

Noble Metals and Alloys

The technical definition of a noble metal is a metal whose potential is highly positive relative to the hydrogen electrode. However, a more practical and simpler description is a metal having a marked resistance to chemical reaction, particularly to oxidation and to attack by organic acids. Because of their high cost, the terms "noble metals" and "precious metals" are more or less synonymous in general usage.

At least eight metals are considered to be noble metals—gold, silver, platinum, palladium, rhodium, ruthenium, osmium, and iridium. Of these, only the first four are considered to be commercially important. For the most part, they offer resistance that is unmatched in base metals and their alloys.

In general, more data are available for the more abundant, more easily fabricated elements. Silver and platinum have been evaluated in more environments than the other noble metals. Conversely, very little data are available for the intractable elements, osmium and ruthenium. Tables 17 to 23 provide corrosion rates for silver, gold, and platinum in various environments.

Silver

Atmospheric and Gaseous Corrosion. Silver resists attack by dry and moist air at ambient temperatures. However, it is very reactive with sulfur bearing gases (i.e., H_2S, SO_2) at ambient and elevated temperatures, forming a black tarnish. The formation of this tarnish significantly reduces the electrical conductivity of silver and thus may compromise it for electrical contacts in these environments. It is also blackened by ozone at a maximum rate of attack between 200 and 250 °C (430 to 480 °F). This black tarnish disappears above 455 °C (850 °F). Silver can be exposed to carbon monoxide up to 300 °C (570 °F), to hydrogen

Table 17 Corrosion of Silver in Acids

Acid	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Acetic, all concentrations	Boiling	<0.05	2
Acetylsalicylic, all concentrations	Boiling	<0.05	2
Aqua regia	Room	Potential dissolution(a)	
Arsenic	Room	Dissolution	
Ascorbic, all concentrations	Room	<0.05	2
Benzoic, all concentrations	130 (265)	<0.05	2
Boric, salt	Boiling	<0.05	2
Butyric	Boiling	<0.05	2
Carbonic, all concentrations	Room	<0.05	2
Chloric, all concentrations	Room	Attacked	
Chlorotoluene-sulfonic	Room	<0.05	2
Chromic, all concentrations	100 (212)	<0.05	2
Citric, to 30% concentration	Boiling	<0.05	2
Crotonic	Boiling	<0.05	2
Fatty acids	400 (750)	<0.05	2
Fluorosilicic	65 (150)	<0.05	2
Formic, pure	Boiling	<0.05	2
Gluconic, all concentrations	Boiling	<0.05	2
Glycerophosphoric, to 50%	Boiling	<0.05	2
Hydrogen selenide	Room	Attacked	
Hydrogen sulfide	Room	Attacked	
Hydrobromic, below 14%	Room	<0.05	2
Hydrochloric		—See Table 2—	
Hydrofluoric, below 50%	Boiling	<0.05	2
Hydroiodic, dilute	Room	<0.25	10
Hypochlorous	Room	Attacked	
Isovaleric, all concentrations	Boiling	<0.05	2
Lactic	Boiling	<0.05	2
Laevulinic, all concentrations	Boiling	<0.05	2
Monochloroacetic, all concentrations	Boiling	<0.05	2
Nitric	Room	Rapid dissolution	
Nitrous	Room	Dissolution	
Oxalic	Boiling	<0.05	2
Phenylacetic, all concentrations	Boiling	<0.05	2
Phosphoric, %			
5	102 (215)	0.003	0.12
45	60 (14)	nil	
45	110 (230)	0.007	0.28
67	60 (140)	0.004	0.16
67	125 (255)	0.02	0.8
85	60 (140)	0.002	0.08
85	140 (285)	0.048	1.9
85	160 (320)	0.306	12
Phthalic, pure	Boiling	<0.05	2
Picric, pure	125 (255)	<0.05	2
Propionic	Boiling	<0.05	2
Pyridine-carboxylic, pure	Room	<0.05	2
Salicylic, all concentrations	Boiling	<0.05	2
Stearic, pure	160 (320)	<0.05	2
Sulfuric, %			
10	Boiling	0.003	0.12
50	Boiling	0.034	1.3
60	Boiling	0.88	34.6
95	Room	0.14	5.5
Sulfurous, all concentrations	90 (195)	<0.05	2
Tartaric, all concentrations(b)	100 (212)	<0.05	2

(a) Attack will occur whenever silver chloride film is ruptured. (b) Oxygen increases attack in dilute tartaric acid at room temperature.

Table 18 Corrosion of Silver in Salts and Other Environments

Environment	Temperature, °C (°F)	Corrosion rate mm/yr	mils/yr
Alum, all concentrations	Boiling	<0.05	2
Aluminum chloride, all concentrations(a)	Boiling	<0.05	2
Aluminum fluoride, all concentrations	Boiling	<0.05	2
Aluminum sulfate, all concentrations	Boiling	<0.05	2
Ammonium chloride, all concentrations	Boiling	<0.05	2
Ammonium hydroxide(b)	Room	<0.05	2
Ammonium nitrate, <20%	Room	<0.05	2
Ammonium phosphate, all concentrations	Boiling	<0.05	2
Ammonium sulfate, all concentrations	Boiling	<0.05	2
Ammonium thiocyanate, pure	100 (212)	<0.05	2
Antimony pentachloride, pure	90 (195)	<0.05	2
Barium chloride, all concentrations	Boiling	<0.05	2
Barium chloride, all concentrations	Room	<0.05	2
Barium peroxide, all concentrations	Room	Attacked	
Bismuth oxide, all concentrations	Room	Slight attack	
Calcium bisulfite, pure	Boiling	<0.05	2
Calcium carbonate, all concentrations	Room	Slight attack	
Calcium chloride, all concentrations	100 (212)	<0.05	2
Calcium hydroxide, all concentrations	100 (212)	<0.05	2
Calcium sulfate, all concentrations	100 (212)	<0.05	2
Calcium sulfide, all concentrations	Room	Blackens	
Cesium hydroxide, all concentrations	500 (930)	<0.05	2
Cupric chloride, all concentrations	100 (212)	Attacked	
Cupric nitrate, all concentrations	Room	<0.05	2
Cupric sulfate, all concentrations	Room-boiling	<0.05	2
Cupric sulfate in sodium chloride	100 (212)	Attacked	
Cuprous chloride, all concentrations	100 (212)	Attacked	
Cuprous nitrate, all concentrations	100 (212)	Attacked	
Cuprous sulfate, all concentrations	100 (212)	Attacked	
Dyes, acid chromium	Boiling	<0.05	2
Ferric alum, all concentrations	100 (212)	Attacked	
Ferric chloride, <5%	Room	<0.05	2
Ferrous sulfate, all concentrations(c)	Room	<0.05	2
Fluorosilicate, all concentrations	100 (212)	<0.05	2
Hydrogen peroxide, all concentrations	Room	Peroxide decomposed	
Hydrogen sulfide, all concentrations	Room	Blackened	
Lithium chloride, all concentrations	Boiling	<0.05	2
Magnesium chloride, all concentrations	120 (250)	<0.05	2
Magnesium chloride, melt	710 (1310)	Attacked	
Mercuric chloride, all concentrations	Room	Not recommended	
Nitrosyl chloride, dry	Room	<0.05	2
Phosphorus chlorides, pure	Boiling	<0.05	2
Potassium bisulfate, all concentrations	Boiling	<0.05	2
Potassium bromide, all concentrations	200–400 (390–750)	<0.05	2
Potassium carbonate, all concentrations	Boiling	<0.05	2
Potassium chlorate, all concentrations	Boiling	<0.05	2
Potassium cyanide, concentrated, in air	Room	Attacked	
Potassium dichromate, all concentrations	Boiling	<0.05	2
Potassium ferrocyanide, all concentrations	Room	Attacked	
Potassium hydroxide, all concentrations(b)	300 (570)	<0.05	2
Potassium hydroxide, melt(b)	350 (680)	<0.05	2
Potassium nitrate, all concentrations	Boiling	<0.05	2
Potassium nitrate, melt	335 (635)	Attacked	
Potassium perborate, all concentrations(d)	50 (120)	<0.05	2
Potassium permanganate, all concentrations	Boiling	Attacked	
Potassium peroxide, melt	100 (212) above melting point	Attacked	
Potassium persulfate, all concentrations	Room	Attacked	
Potassium sulfate, all concentrations	Boiling	<0.05	2
Sodium bisulfate, melt	400 (750)	Attacked	
Sodium bisulfites, all concentrations	100 (212)	<0.05	2
Sodium carbonate	Boiling	<0.05	2
Sodium chloride, all concentrations	Boiling	<0.05	2
Sodium chromate, all concentrations	Boiling	<0.05	2
Sodium cyanide, all concentrations	Room	Attacked	
Sodium fluorosilicate, pure	100 (212)	<0.05	2
Sodium hydroxide, <95%	Boiling	<0.05	2
Sodium hydroxide, melt(b)(e)	500 (930)	<0.05	2
Sodium hypochlorite, all concentrations	Room	<0.05	2
Sodium hypochlorite plus sodium chloride, saturated solution	Room	<0.05	2
Sodium nitrate, all concentrations	Boiling	<0.05	2
Sodium perborate, all concentrations	50 (120)	<0.05	2
Sodium perchlorate, all concentrations	Boiling	<0.05	2
Sodium perchlorate, melt	480 (900)	Attacked	
Sodium peroxide, melt	400 (750)	Attacked	
Sodium phosphates, all concentrations	Boiling	<0.05	2
Sodium silicates, all concentrations	Boiling	<0.05	2
Sodium sulfate, all concentrations	Boiling	<0.05	2
Sodium sulfide, all concentrations	Room	Slight attack	
Sodium thiosulfate, all concentrations	Room	<0.05	2
Stannic ammonium chloride, all concentrations	Boiling	<0.05	2
Stannic chloride, all concentrations	Boiling	<0.05	2
Sulfuryl chloride, dry and wet	300 (570)	<0.05	2
Thionyl chloride, dry or wet	Boiling	<0.05	2
Uranyl nitrate, all concentrations	Boiling	<0.05	2
Zinc chloride, all concentrations	Boiling	<0.05	2

(a) Provided oxidizing agents are not present. (b) Air must be excluded. (c) Attacked upon heating. (d) Causes deterioration of potassium perborate. (e) Mass transfer possible above 600 °C (1110 °F)

to 700 °C (1290 °F) and to nitrogen to 500 °C (930 °F) without attack.

At elevated temperatures, silver may form a thin film of silver oxide when exposed to air, but above 455 °C (850 °F), the oxide dissociates, leaving the surface clean.

Chemical Corrosion. Silver has been used for years in the production of a number of chemical and food products where it has a high degree of corrosion resistance, or where very high purity of product is required.

Silver shows a higher degree of resistance to high-temperature caustic alkalis than most other metals. It is used for evaporating pans in the concentration of sodium hydroxide to the anhydrous melt in the production of chemically pure grades of caustic soda.

Silver has a high degree of resistance to hot, concentrated organic acids such as acetic, formic, citric, lactic, fumaric, phthalic, and benzoic acids, fatty acids, and phenol.

The metal is also used extensively in cases where halogens or halogen acids are involved. One of the most important of these is in handling wet chlorine gas in water-purification installations. It is also used in service with aqueous hydrochloric acid, particularly when the acid is associated with organic hydrocarbon liquids in pressure vessels and process equipment. Resistance of silver to dilute hydrofluoric acid conditions usually is best where there is only a slight possibility for removal of the protective chloride films.

Silver shows a high degree of resistance to boiling hydrofluoric acid solutions of all concentrations when these solutions do not contain any sulfur compounds or sulfuric acid. Silver-tubed condensers are used for condensing 70% hydrofluoric acid from the hot HF vapors formed in the hydrofluorination of uranium compounds.

Table 19 Corrosion of Silver in Organic Compounds

Environment	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Acetaldehyde, pure	200–400 (390–750)	<0.05	2
Acetic anhydride, all concentrations	Boiling	<0.05	2
Acetone, pure	Boiling	<0.05	2
Acetylene dichloride, wet and acid	Boiling	<0.05	2
Ethyl alcohol, all concentrations	Boiling	<0.05	2
Amyl acetate, pure	Boiling	<0.05	2
Amyl alcohol, pure	Boiling	<0.05	2
Aniline, pure	Boiling	<0.05	2
Benzaldehyde, pure and aqueous	Boiling	<0.05	2
Benzene, pure	Boiling	<0.05	2
Benzotrifluoride, pure	Boiling	<0.05	2
Benzyl chloride, pure	180 (355)	<0.05	2
-bromoisovaleryl bromide, pure	100 (212)	<0.05	2
-bromoisovaleryl urea, pure	Melting point	<0.05	2
Butyl acetate, pure	Boiling	<0.05	2
Butyl alcohol, pure	Boiling	<0.05	2
Carbon tetrachloride, dry and wet	Boiling	<0.05	2
Chlorobenzene, pure	Boiling	<0.05	2
Chlorocresols, all concentrations	Boiling	<0.05	2
Chloroform, dry or wet	Boiling	<0.05	2
Chlorohydrins, pure	Boiling	<0.05	2
Chloronitrobenzenes, pure	Boiling	<0.05	2
Chlorotoluene, pure	Boiling	<0.05	2
Coniferyl alcohol, all concentrations	80 (175)	<0.05	2
Copals, pure and wet	400 (750)	<0.05	2
Copper acetate, neutral solutions	100 (212)	<0.05	2
Copper acetate, ammoniacal solutions	Room	Attacked	
Coumarin, pure	100 (212)	<0.05	2
Cresols, pure	Boiling	<0.05	2
Dextrose, all concentrations	Boiling	<0.05	2
Dialkyl sulfates, pure	Boiling	<0.05	2
Dibutyl phthalate, pure	Boiling	<0.05	2
Dimethylaniline, pure	Boiling	<0.05	2
Diphenyl, pure	400 (750)	<0.05	2
Essential oils, pure(a)	Boiling	<0.05	2
Ether, pure	Boiling	<0.05	2
Ethyl acetate, pure	Boiling	<0.05	2
Ethyl benzene, pure	136 (277)	<0.05	2
Ethylene dibromide, wet and acid products	Boiling	<0.05	2
Ethylene dichloride, wet and acid products	Boiling	<0.05	2
Fats, pure	300 (570)	<0.05	2
Fatty acids, pure	400 (750)	<0.05	2
Formaldehyde, all concentrations	Boiling	<0.05	2
Furfural, wet and slightly acid	Boiling	<0.05	2
Gelatin, pure	Boiling	<0.05	2
Glycerol, pure	Boiling	<0.05	2
Guanidine nitrate, all concentrations	Room	Not recommended	
Guinolines, pure	Boiling	<0.05	2
Guinone, inorganic solvent and pure	100 (212)	<0.05	2
Hexachloroethane, dry and moist	187 (369)	<0.05	2
Hexamethylene tetramine, all concentrations(b)	Room	<0.05	2
Hydrazine, pure	Room	Not recommended	
Hydroguinone, pure	Boiling	<0.05	2
Isoborneol acetate, pure	Boiling	<0.05	2
Isobutyl chloride, dry and wet	Boiling	<0.05	2
Limonene, pure	Boiling	<0.05	2
Methyl alcohol, pure	Boiling	<0.05	2
Methylamines, aqueous	Room	Attacked	
Methyl chloride, dry and wet	300 (570)	<0.05	2
Methylene chloride, dry and wet	Boiling	<0.05	2
Methylglycol, pure	Boiling	<0.05	2
Milk, pure(c)	Boiling	<0.05	2
Nitrobenzene, pure	Boiling	<0.05	2
Nitrocellulose, in water or alcohol	Room	<0.05	2
Nitrophenols, pure	Boiling	<0.05	2
Nitrotoluenes, pure	Boiling	<0.05	2
Pentachloroethane, wet, dry, and acid	Boiling	<0.05	2
Phenol, all concentrations	Boiling	<0.05	2
Phthalic anhydride, pure	Boiling	<0.05	2
Potassium acetate, all concentrations	Boiling	<0.05	2
Quinine sulfate, all concentrations	70 (160)	<0.05	2
Sodium acetate, all concentrations	Boiling	<0.05	2
Sodium acetate, melt	400 (750)	<0.05	2
Sodium bisulfate, all concentrations	Boiling	<0.05	2
Sodium formate, all concentrations	Boiling	<0.05	2
Sodium isovalerate, all concentrations	Boiling	<0.05	2
Sodium isovalerate, melt with sodium hydroxide	290 (555)	<0.05	2
Sodium methylate, all concentrations in alcohol or ether	100 (212)	<0.05	2
Sodium pentachlorophenolate, all concentrations	Boiling	<0.05	2
Sodium phenolate, all concentrations	Boiling	<0.05	2
Sodium salicylate, all concentrations	Boiling	<0.05	2
Sodium tartrates, all concentrations	Boiling	<0.05	2
Sorbital, all concentrations	Boiling	<0.05	2
Sorbose, all concentrations	Boiling	<0.05	2
Toluene, pure	Boiling	<0.05	2
Toluenesulfonyl chlorides, pure	Boiling	<0.05	2
Triethanolamine, mixture with diethylene glycol	Room	<0.05	2
Vinyl chloride, pure	200 (390)	<0.05	2

(a) Silver may taint the flavor of fats. (b) Solutions must be free of air and ammonia. (c) Silver may impart metallic taste

Silver resists anhydrous hydrogen fluoride gas at considerably elevated temperatures. It resists hydrogen chloride gas up to about 225 °C (435 °F), but is not resistant to chlorine gas above room temperature.

Gold

Oxidation Resistance. Pure gold owes its corrosion resistance to its inherently low chemical affinity for the other elements. Passive film protection usually does not occur. Therefore, gold is impervious to attack by virtually any atmosphere.

Acids. Gold is resistant to H_2SO_4 to 250 °C (480 °F); attack above this temperature may be primarily dependent on available oxygen. Gold is also resistant to concentrated HCl to its boiling point and also to HNO_3 concentrations of up to 50% at the boiling point. However, hot mixtures of HNO_3O and H_2SO_4 will rapidly attack gold, as well as aqua regia and hydrogen cyanide (with oxygen present). Mixtures of HCl, HBr, and HI with HNO_3 are extremely corrosive to gold. Mixtures of HF and HNO_3 are not corrosive to gold. Gold resists most other acids.

Chemicals. Because of its softness and lack of resistance to halogens, the use of gold in chemical applications is somewhat limited. Gold is resistant to nonoxidizing H_3PO_4 and phosphates; therefore, it is used for lining autoclaves handling phosphate mixtures up to 500 °C (939 °F). In the production of zirconium by the iodide process, gold closure gaskets are used to handle dry iodine vapors at 500 °C (939 °F). The use of gold-lined equipment to perform hydroclorinations and hydrofluorinations of organic compounds in the chemical industry is well established.

Platinum

Atmospheric Corrosion. The exceptional resistance of platinum is well known. It is one of the few metals unaffected

Table 20 Corrosion of Gold in Acids

Acid	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Acetic, glacial	100 (212)	<0.05	2
Aqua regia	Room	Rapid dissolution	
Arsenic, all concentrations	Room	<0.05	2
Chlorosulfonic, all concentrations	Boiling	<0.05	2
Chlorotoluene-sulfonic, all concentrations	Boiling	<0.05	2
Citric, 20%	Boiling	<0.05	2
Citric, 30%	Boiling	<0.05	2
Crotonic, all concentrations	Boiling	<0.05	2
Fatty acids, pure	Boiling	<0.05	2
Glycerophosphoric, 1 to 50%	Boiling	<0.05	2
Hydrobromic, specific gravity 1.7	Room	<0.05	2
Hydrochloric, 36%	Room-100 (212)	<0.05	2
Hydrofluoric, 40%	Room	<0.05	2
Hydrogen sulfide, moist	Room	<0.05	2
Hydroiodic, specific gravity 1.75	Room	<0.05	2
Isovaleric, all concentrations	Boiling	<0.05	2
Lactic, all concentrations	Boiling	<0.05	2
Laevulinic, all concentrations	Boiling	<0.05	2
Nitric, %			
1–50	Boiling	<0.05	2
70	Room	>0.05	2
70	Boiling	0.15	6
Oxalic, all concentrations	Boiling	<0.05	2
Phenol-2,4-disulfonic, all concentrations	100 (212)	<0.05	2
Phthalic, pure	Boiling	<0.05	2
Picric, pure	125 (255)	<0.05	2
Propionic, all concentrations	Boiling	<0.05	2
Pyridine, all concentrations	Boiling	<0.05	2
Pyridine-carboxylic, all concentrations	150 (300)	<0.05	2
Salicylic, all concentrations	Boiling	<0.05	2
Stearic, pure	Boiling	<0.05	2
Sulfuric, all concentrations	250 (480)	<0.05	2
Sulfurous, all concentrations	100 (212)	<0.05	2
Tartaric, all concentrations	Boiling	<0.05	2

by atmospheric exposure, in virtually any atmosphere including severe industrial and saline environments.

Chemical Corrosion. Platinum is resistant to corrosion by single acids, alkalis, aqueous solutions of common salts, and organic materials. The potential pH diagram for the metal as defined by Pourbaix shows that platinum at 25 °C (75 °F) is immune to attack at all but the lowest pH levels and high redox potentials. Even at elevated temperatures, platinum is resistant to dry hydrogen chloride and sulfurous gases. Platinum is resistant to most halogen gases at room temperature, with dry and moist bromine being the exception. Platinum is also essentially inert to many molten salts, and it resists the action of fused glasses if oxidizing conditions are maintained.

Aqua regia and mixtures of HCl and oxidizing agents will attack platinum, as will free halogens and selenic acid to some degree at elevated temperatures.

Alloying Effects on Corrosion Resistance. Alloys containing up to 25% palladium have essentially the same corrosion resistance as platinum, and they are not discolored by heating in air. The corrosion resistance of the entire binary series of rhodium-platinum alloys is excellent, with corrosion resistance tending to improve with higher rhodium content.

All alloys of the gold-platinum binary system remain quite corrosion resistant. Alloys containing more than 60% gold are rapidly attacked by HNO_3 and $FeCl_3$ and are tarnished by exposure to industrial atmospheres.

Palladium

Applications. Palladium applications are limited. Alloyed with rhodium, gold, or platinum, it is used for nonoxidizing electrical contacts and thermocouples. Alloyed with platinum, it is used for contact screens in the ammonia oxidation process and for laboratory ware. In dental prosthesis, medical techniques, and also in jewelry making, palladium-base alloys are often used.

Atmospheric Corrosion. In many respects, palladium resembles platinum and gold, and many comparisons can be drawn regarding physical properties and behavior. Palladium resists attack in virtually all atmospheres including industrial and saline; this remains true even in the presence of hydrogen. In general, however, palladium is less resistant to corrosion than platinum, especially in atmospheres that are strongly oxidizing.

Chemical Corrosion. Palladium is generally resistant to corrosion by most single acids, alkalis, and aqueous solutions of many common salts. It is not attacked at room temperature by H_2SO_4, HCl, HF, acetic, or oxalic acids, although it may experience the effects of such attack at 100 °C (212 °F), or when air is present. Nitric and hot H_2SO_4 attack palladium, as do FeCl and hypochlorite solutions, chlorine, bromine, and, to a negligible extent, iodine.

Table 21 Corrosion of Gold in Salts

Salt	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Aluminum sulfate, 10%	100 (212)	<0.05	2
Ferric chloride in HCl solutions	Room	<0.25	10
Magnesium chloride, all concentrations	Boiling	<0.05	2
Mercuric chloride, 10%	100 (212)	50.0	2000
Nitrosyl chloride, dry	Room	<0.05	2
Potassium bisulfate, all concentrations	Boiling	<0.05	2
Potassium bromide, all concentrations	Boiling	<0.05	2
Potassium carbonate, all concentrations	Boiling	<0.05	2
Potassium chlorate, all concentrations	Boiling	<0.05	2
Potassium dichromate, all concentrations	Boiling	<0.05	2
Potassium hydroxide, all concentrations	300 (570)	<0.05	2
Potassium hydroxide, melt	360 (680)	<0.05	2
Potassium iodide, with iodine	Room	Attacked	
Potassium nitrate, all concentrations	Boiling	<0.05	2
Potassium permanganate, all concentrations	Boiling	<0.05	2
Potassium peroxide, melt	380 (715)	Attacked	
Potassium sulfate, all concentrations	Boiling	<0.05	2
Sodium bisulfate, all concentrations	Boiling	<0.05	2
Sodium bisulfate, melt	400 (750)	<0.05	2
Sodium bisulfites, all concentrations	100 (212)	<0.05	2
Sodium carbonate, all concentrations	Boiling	<0.05	2
Sodium chloride, all concentrations	Boiling	<0.05	2
Sodium chromate, all concentrations	Boiling	<0.05	2
Sodium cyanide, all concentrations	Room	Attacked	
Sodium hydroxide, <90%	Boiling	<0.05	2
Sodium nitrate, all concentrations	Boiling	<0.05	2
Sodium perborate, all concentrations	50 (120)	<0.05	2
Sodium phosphates, all concentrations	Boiling	<0.05	2
Sodium silicates, all concentrations	Boiling	<0.05	2
Sodium sulfate, all concentrations	Boiling	<0.05	2
Sodium sulfide, all concentrations	Boiling	<0.05	2
Sodium sulfite, all concentrations	Boiling	<0.05	2
Stannic ammonium chloride, all concentrations	Boiling	<0.05	2
Stannic chloride, all concentrations	Boiling		
Strontium nitrate, all concentrations	Boiling	<0.05	2
Sulfur monochloride, pure	Boiling	<0.05	2
Sulfuryl chloride, dry and wet	300 (570)	<0.05	2
Thionyl chloride, dry or wet	Boiling	<0.05	2
Uranyl nitrate, all concentrations	Boiling	<0.05	2
Zinc sulfate, 10%	100 (212)	<0.05	2

Table 22 Corrosion of Platinum in Acids

Acid	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Acetic, all concentrations	Boiling	<0.05	2
Acetylsalicylic, all concentrations	Boiling	<0.05	2
Aqua regia	Room	Rapid dissolution	
Ascorbic, all concentrations	Boiling	<0.05	2
Benzoic, all concentrations	130 (265)	<0.05	2
Benzene sulfonic, pure	Room	<0.05	2
Boric, saturated	Boiling	<0.05	2
Butyric, all concentrations	Boiling	<0.05	2
Carbonic, pure	1400 (2550)	<0.05	2
Chloric, all concentrations	Room	<0.05	2
Chlorosulfonic, all concentrations	Boiling	<0.05	2
Chlorotoluene-sulfonic, all concentrations	Boiling	<0.05	2
Citric, <20% concentrations	Boiling	<0.05	2
Citric, 30% concentrations	Boiling	<0.05	2
Crotonic, all concentrations	Boiling	<0.05	2
Fatty, pure	400 (750)	<0.05	2
Fluorosilicic (10% hydrofluoric, 5% fluorosilicic)	Boiling	<0.05	2
Formic, pure	Boiling	<0.05	2
Gluconic, all concentrations	Boiling	<0.05	2
Glycerophosphoric, 1–50% solution	Boiling	<0.05	2
Hydrobromic, fuming	Room	<0.25	10
	100 (212)	4.8	189
Hydrochloric, 36%	Room	nil	
	100 (212)	<0.25	10
Hydrofluoric, 40%	Room	nil	
Hydrogen sulfide, pure	1000 (1830)	<0.05	2
Hydroiodic, specific gravity 1.75	Room	<0.25	10
	100 (212)	13.7	539
Isovaleric, all concentrations	Boiling	<0.05	2
Lactic, all concentrations	Boiling	<0.05	2

(Continued)

Table 22 (continued)

Acid	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Laevolinic, all concentrations	Boiling	<0.05	2
Monochloroacetic, all concentrations	Boiling	<0.05	2
Nitric, 70%	Room	<0.25	10
Nitric, 95%	Room-100 (212)	nil	
Nitrosyl-sulfuric, pure	100 (212)	<0.05	2
Oxalic, all concentrations	Boiling	<0.05	2
Phenol-2,4-disulfonic, all concentrations	100 (212)	<0.05	2
Phenylacetic, all concentrations	Boiling	<0.05	2
Phosphoric, 100 g/L	100 (212)	nil	
Phthalic, pure	Boiling	<0.05	2
Picric, pure	125 (255)	<0.05	2
Propionic, all concentrations	Boiling	<0.05	2
Pyridine, all concentrations	Boiling	<0.05	2
Pyridine-carboxylic, all concentrations	150 (300)	<0.05	2
Salicylic, all concentrations	Boiling	<0.05	2
Stearic, pure	Boiling	<0.05	2
Sulfuric	Room-100 (212)	nil	
Sulfurous, all concentrations	100 (212)	<0.05	2
Tartaric, all concentrations	Boiling	<0.05	2

Table 23 Corrosion of Platinum in Salts

Salt	Temperature, °C (°F)	Corrosion rate mm/yr	Corrosion rate mils/yr
Alum, all concentrations	Boiling	<0.05	2
Aluminum chloride, all concentrations	Boiling	<0.05	2
Aluminum fluoride, all concentrations	Boiling	<0.05	2
Aluminum sulfate, 100 g/L	Room-100 (212)	nil	
Aluminum sulfate, all concentrations	Boiling	<0.05	2
Ammonium chloride, all concentrations	Boiling	<0.05	2
Ammonium nitrate, all concentrations	Boiling	<0.05	2
Ammonium persulfate, all concentrations	60 (140)	<0.05	2
Ammonium phosphate, all concentrations	Boiling	<0.05	2
Ammonium sulfate, all concentrations	Boiling	<0.05	2
Ammonium thiocyanate, pure	Boiling	<0.05	2
Antimony pentachloride, pure	100 (212)	<0.05	2
Barium chloride, all concentrations	Boiling	<0.05	2
Calcium hypochlorite, all concentrations	Room	<0.05	2
Calcium bisulfite, pure	Boiling	<0.05	2
Calcium chloride, all concentrations	100 (212)	<0.05	2
Calcium sulfate, pure	To red heat	<0.05	2
Calcium sulfide, all concentrations	100 (212)	<0.05	2
Calcium tungstate, pure	800 (1470)	<0.05	2
Calcium tungstate, all concentrations	Boiling	<0.05	2
Carnallite, pure	500 (930)	<0.05	2
Carnallite, all concentrations	Boiling	<0.05	2
Carnallite, saturated solution	Boiling	<0.05	2
Cupric chloride, 100 g/L	Room	nil	
Cupric sulfate, 100 g/L	100 (212)	nil	
Ferric chloride, 100 g/L	Room	<0.25	10
	100 (212)	16.7	657
Ferrous sulfate, all concentrations	Room	<0.05	2
Fluorosilicate, all concentrations	100 (212)	<0.05	2
Lithium chloride, all concentrations	Boiling	<0.05	2
Magnesium chloride, all concentrations	Boiling	<0.05	2
Magnesium sulfate, all concentrations	100 (212)	<0.05	2
Mercury chloride, all concentrations	Boiling	<0.05	2
Nitrosyl chloride, dry	Room	<0.05	2
Phosphorus chlorides, pure	Boiling	<0.05	2
Potassium bisulfate, all concentrations	Boiling	<0.05	2
Potassium bisulfate, melt	200–400 (390–750)	<0.05	2
Potassium bromide, all concentrations	Boiling	<0.05	2
Potassium bromide, melt	760 (1400)	<0.05	2
Potassium carbonate, all concentrations	Boiling	<0.05	2
Potassium carbonate, melt(a)	900 (1650)	<0.05	2
Potassium chlorate, all concentrations(b)	Boiling	<0.05	2
Potassium cyanide, 50 g/L	Room	<0.25	10
	100 (212)	1.4	55
Potassium dichromate, all concentrations	Boiling	<0.05	2
Potassium ferricyanide, all concentrations	Boiling	<0.05	2
Potassium ferrocyanide, all concentrations	Boiling	<0.05	2
Potassium hydroxide, all concentrations	300 (570)	<0.05	2
Potassium hydroxide, melt(a)	300 (570)	<0.05	2
Potassium nitrate, all concentrations	Boiling	<0.05	2
Potassium nitrate, melt	335 (635)	Attacked	
Potassium permanganate, all concentrations	Boiling	<0.05	2
Potassium peroxide, all concentrations	100 (212)	<0.05	2
Potassium peroxide, melt	380 (715)	Attacked	
Potassium persulfate, all concentrations	60 (140)	Attacked	
Potassium sulfate, all concentrations(c)	Boiling	<0.05	2
Potassium sulfate, melt	Melting point	<0.05	2
Sodium bisulfate, all concentrations	Boiling	<0.05	2
Sodium bisulfate, melt	400 (750)	<0.05	2
Sodium bisulfites, all concentrations	100 (212)	<0.05	2
Sodium carbonate, all concentrations	Boiling	<0.05	2
Sodium carbonate, melt	860 (1580)	<0.05	2
Sodium chloride, all concentrations	Boiling	<0.05	2
Sodium chloride, melt(d)	800 (1470)	<0.05	2
Sodium chromate, all concentrations	Boiling	<0.05	2
Sodium cyanide, all concentrations	Room	<0.05	2
Sodium formaldehyde sulfoxylate, all concentrations	90 (195)	<0.05	2
Sodium formate, all concentrations	Boiling	<0.05	2
Sodium formate, melt	260 (500)	<0.05	2
Sodium fluorosilicate, all concentrations	100 (212)	<0.05	2
Sodium hydroxide, <90% pure	Boiling	<0.05	2
Sodium hydroxide, melt	350 (660)	<0.05	2
Sodium hypochlorite, all concentrations	100 (212)	<0.05	2
Sodium hypochlorite + sodium chloride, saturated solution	100 (212)	<0.25	10
Sodium nitrate, all concentrations	Boiling	<0.05	2
Sodium perborate, all concentrations	50 (120)	<0.05	2
Sodium percarbonate, all concentrations	50 (120)	<0.05	2
Sodium perchlorate, all concentrations	Boiling	<0.05	2
Sodium perchlorate, melt	480 (900)	Attacked	
Sodium peroxide, all concentrations	Boiling	<0.05	2
Sodium peroxide, melt	400 (750)	<0.05	2
Sodium phosphates, all concentrations	Boiling	<0.05	2
Sodium silicates, all concentrations	Boiling	<0.05	2
Sodium sulfate, all concentrations	Boiling	<0.05	2
Sodium sulfide, all concentrations	Boiling	<0.05	2
Sodium sulfide, melt	700 (1290)	<0.05	2
Sodium sulfite, all concentrations	Boiling	<0.05	2
Sodium thiocyanate, all concentrations	Boiling	<0.05	2
Sodium thiocyanate, melt	300 (570)	<0.05	2
Sodium thiosulfate, all concentrations	Boiling	<0.05	2
Stannic ammonium chloride, all concentrations	Boiling	<0.05	2
Stannic chloride, all concentrations	Boiling	<0.05	2
Strontium nitrate, all concentrations	Boiling	<0.05	2
Sulfite cooking liquor, pH 1.3	Boiling	<0.05	2
Sulfur monochloride, pure	Boiling	<0.05	2
Sulfuryl chloride, dry and wet	300 (570)	<0.05	2
Thionyl chloride, dry or wet	Boiling	<0.05	2
Uranyl nitrate, all concentrations	Boiling	<0.05	2

(a) Platinum is attacked if strong oxidizers are present. (b) Platinum-iridium anodes used to electrolytically manufacture potassium chlorate. (c) Provided reducing agents are not present. (d) Provided no ammonia is present

Uranium

The environments of primary importance involving the corrosion of uranium are those atomic/nuclear conditions that result from contact with the metal at high temperatures during the malfunction of reactors, as for example water, carbon dioxide, carbon monoxide, air, and steam. In each case, corrosion is favored by large free energy and heat terms for the formation of uranium oxides. The major use of uranium in reactors that are cooled by carbon dioxide has resulted in emphasis on the behavior of uranium in this gas and, to a lesser extent, in carbon monoxide and air. At the same time, other basic corrosion studies emphasize the more traditional environments.

Atmospheric Corrosion

In the atmosphere and at room temperature, uranium readily tarnishes. Electropolishing inhibits the tarnishing process; etching in nitric acid activates the surface. Uranium dioxide and hydrated UO_3 are the principal solid products.

This corrosion is enhanced by water vapor, and thus, the process is controlled by humidity levels. However, the presence of oxygen markedly inhibits attack by water vapor. It is thought that the corrosion is electromechanical in nature, with hydrated UO_3 being formed at cathodic areas.

There is a relationship between percent of alloying additions and corrosion response in hot, humid air. In general, decreasing the total amount of alloying additions, irrespective of the alloying element, increases the resistance to corrosion.

Water

Various recent studies center on the relative resistance of numerous uranium alloys to boiling water at 100 *C (212 *F). It has been shown that the corrosion resistance of uranium alloys to boiling water is inversely proportional to the percentage of alpha uranium present in the particular composition. An increase in the corrosion resistance with alloying is due to the formation of the gamma phase. The most promising alloying additives (molybdenum, niobium, and zirconium) have been extensively studied.

Dilute Salt Solutions

Because the corrosion resistance of uranium alloys in hot, moist air and in boiling water has been found to be proportional to the total alloying content, it is expected that this proportionality also holds true for corrosion in dilute salt solutions. Electrochemical measurements have indicated that this should be the case. In one study, standard or corrosion potentials of various uranium alloys were measures in a 0.0001*M* potassium chloride (KCl) solution against a saturated calomel electrode. Although the measured potentials versus the total alloying content of the alloys do not produce a strictly linear relationship, the two are directly related. Kinetic data on the corrosion rates of uranium alloys in dilute salt solutions are scarce, but those that have been published confirm this relationship.

Seawater

As with the preceding corrosion environments, the corrosion susceptibility of uranium alloys in seawater is expected to decrease with increasing alloy content. In one investigation, the corrosion potentials of a number of uranium alloys were measured in artificial seawater. The observed trend of decreasing corrosion potential with increasing alloying content is very similar to that discussed previously for dilute salt solutions. Thermodynamics predict a decreasing corrosion rate with increased alloy content. The kinetics of the uranium alloy/seawater reaction were measured galvimetrically; the results showed a logarithmic relationship between the corrosion rate and the total alloy content.

Acids and Bases

An indication of the possible anodic reactions can be obtained by examining a typical Pourbaix diagram for uranium. In the potential range from -1.8 to 1.2 V at low pH (0 to 2.0), uranium forms primarily soluble species. The uranium ion U^{3+} forms the active region near the corrosion potential, and the uranyl ion forms in the transpassive region. In the passive region, UO_2 undoubtedly forms. Anodic polarization techniques can be used to study the ease of transition from the active to the passive state, as well as the dissolution behavior of the metal and its alloys. The transition from the active to the passive state is accompanied by a decrease in corrosion rate on the order of 10^4 to 10^6, which is extremely significant for many applications.

Anodic polarization techniques have been used to study the effects of alloying constituent, temperature, solution composition, solution concentration, pH, and the presence of chloride on the corrosion response of uranium alloys. One of the figures here shows an example of the effect of alloying on anodic polarization; the passive current densities vary inversely with alloying content. Another of the figures shows an example of the effect of solution composition, particularly the addition of chloride, on the anodic polarization behavior. The uranium-molybdenum alloy passivates more easily in sodium sulfate (Na_2SO_4) than in sulfuric acid (H_2SO_4), and the addition of chloride prevents passivation entirely.

Additional conclusions have been reached based on this work, as follows. Uranium binary alloys exhibit active-passive behavior in sodium hydroxide, ammonium hydroxide, sodium nitrate, sodium chromate, and ammonium chromate. The critical current densities for passivity were inversely proportional to the H_2SO_4 concentration. Unlike those of most metals, the dissolution rates of uranium alloys decrease with increasing acid concentration. Chloride additions as small as 0.005*M* affect the anodic polarization curve, but chromates,

sulfates, and nitrates inhibit pitting at this low chloride concentration. The uranium-titanium alloys were found to be more resistant to basic solutions than uranium-molybdenum alloys.

Cemented Carbides

The corrosion of cemented carbides is based on the solubility of the key ingredients used in the various compositions. Although some alloying occurs, the solubility of the tungsten carbide-cobalt (WC-Co) and titanium carbide (TiC) in cobalt or nickel is very limited. The main alloying in the WC-Co compositions is primarily based on the addition of TiC, TaC, and NbC, which form cubic phase solid solutions with WC.

Corrosion of cemented carbides is generally based on the surface depletion of the binder phase such that at the surface region only a carbide skeleton remains. Because the applications are invariably for wear or abrasion, this skeleton is rapidly worn away. At low binder phase contents, the rate of attack is diminished, and in conditions in which the corrosion is not too severe, the reduced binder content will be beneficial. In more severe corrosion, however, the use of a cobalt binder is prohibited, and the WC-Co grade is simply not resistant enough. In these cases, certain corrosion-resistant grades should be used. Table 24 provides data on the corrosion resistance of cemented carbides in various media.

The most common of the corrosion-resistant grades are WC with nickel alloy binders and TiC-Ni-Mo_2C-base cemented carbide. Various data indicate that the corrosion rate as a function of pH for these grades tested in buffered solutions. These data show that straight WC-Co grades are resistant down to pH 7. This is also valid for WC-Co grades containing cubic carbides such as TiC, TaC, and NbC. The highest corrosion resistance is obtained for certain alloyed TiC-Ni grades, which are resistant down to about pH 1. When compared, however, with straight WC-Co grades, they are less tough and have lower thermal conductivity. They also have several other disadvantages.

In many corrosion-wear conditions, the proper choice is specially alloyed WC-Ni grades, which are resistant down to pH 2 to 3. Even in certain solutions with pH values less than 2, they have proved to be resistant to corrosion.

Although the pH value is one of the most important parameters when determining the corrosivity of a medium, there are other factors of great influence. These include temperature and electrical conductivity. This latter is dependent on the ion concentration, that is, the amount of dissolved salts in the solution. Thus, a simple definition of corrosivity in a given medium cannot be given. Accordingly, no general rules are valid in all situations.

Acids

In general, it can be stated that the corrosion of cemented WC is fair to good in a limited way in all acids except HNO_3. The corrosion resistance of cemented TiC is excellent in phosphoric acid (H_3PO_4), boric acid, and picric acid. It is somewhat better than cemented WC in HCl or sulfuric acid (H_2SO_4). Cemented TiC exhibits poor corrosion resistance in HNO_3. As expected, increasing the cobalt content to increase strength significantly decreases the corrosion resistance. The same situation exists in virtually all corrosive environments.

Special Grades

To obtain corrosion resistance above and beyond that available with regular WC-Co and TiC-Ni grades, the special corrosion-resistant grades are used. Although they introduce disadvantages, these grades do offer resistance in many media.

Warm Acids and Bases

The straight WC-Co compositions show rapid attack in dilute H_2SO_4 and HNO_3, and little attack in those concentrated acids. Although the corrosion rate is lower in HCl, it is obvious that these compositions are not suitable for use in warm or hot acid solutions. The TiC-6.5Mo composition is quite good in H_2SO_4, moderately good in HCl, and very poor in HNO_3. Several of the binderless compositions and the TaC-base cemented carbide show very acceptable corrosion resistance in these warm acids. These results are to be expected, because the cobalt and nickel binders are completely soluble in these acids.

The corrosion rates of various cemented carbides in basic solutions at 50 °C (120 °F) are an entirely different matter. Although corrosion does proceed, it is slow enough to demonstrate the utility of even the WC-Co compositions in such applications as seal rings in these basic solutions.

Table 24 Corrosion Resistance of Cemented Carbides in Various Media

Data for two AISI austenitic stainless steels are included for comparison.

Medium	Chemical designation	Concentration, %	Temperature, °C (°F)	pH	Type of cemented carbide/corrosion resistance(a)					AISI stainless steels(b)	
					WC-Co	TiC-NiMo	WC-Ni	WC-CoCr	WC-TaC-Co	Type 302	Type 316
Acetic acid, unaerated	CH_3COOH	4	Room	...	C	B	B	B	A	...	...
Acetic acid (glacial), unaerated	CH_3COOH	99.8	Room	...	C	C	B	A	A	...	...
Acetone	$(CH_3)_2CO$	...	Room	...	A	A	A	A	A	A	A
Alcohols	...	...	Room	...	A	A	A	A	A	...	...
Ammonia, anhydrous	NH_3	...	...	...	B	B	B	B	A	...	...
Argon gas	Ar	...	...	...	A	A	A	A	A	...	...
Benzene, liquid	C_6H_6	...	Room	...	A	A	A	A	A	...	...
Carbon tetrachloride	CCl_4	Pure	Room	...	A	A	A	A	A	...	...
Chlorine gas, dry	Cl	...	Room	...	C	C	C	C	B	...	...
Chlorine gas, wet	$Cl{\cdot}H_2O$	...	Room	...	D	C	C	D	B	...	...
Citric acid	$C_3H_4(OH)(COOH)_3$	5	Room	1.7	C	A	A	...	...	A	A
Citric acid	$C_3H_4(OH)(COOH)_3$	5	60 (140)	1.7	D	A	B	...	...	A	A
Copper sulfate solution	$CuSO_4$	0.01	Room	6	C	A	A	...	...	A-C	A-C
Copper sulfate solution	$CuSO_4$	0.01	70 (160)	6	D	A	A	...	...	A-C	A-C
Digester liquor, black	...	...	66 (150)	...	B	B	B	B	A	...	...
Esters	...	...	Room	...	A	A	A	A	A	...	...
Ethanol	C_2H_5OH	96	Room	...	A	A	A	...	...	A	A
Ethylene glycol	$C_2H_6O_2$	...	Room	...	A	A	A	A	A	...	...
Ferrous sulfide	FeS	Slurry in water	Room	...	C	C	C	C	A	...	...
Fluorine, liquid	F	...	−188 (−305)	...		B					
50% formaldehyde, 50% alcohol	...	...	Room	...	C	Uncoupled B Coupled C(c)	C	C	A	...	...
Formic acid	HCOOH	5	Room	...	C	A	C	...	...	A	A
Formic acid	HCOOH	5	60 (140)	1.8	D	A	...	...	...	B	A
Freon gas	$C_2Cl_3F_3/CH_2Cl_3$	...	Room	...	A	A	A	A	A	...	...
Gasoline	...	...	Room	...	A	A	A	A	A	...	...
Helium, liquid	He	...	−269 (−450)	...	A	A	A	A	A	...	...
Hydrochloric acid	HCl	0.5	Room	1	D	C	C	...	...	C	A
Hydrochloric acid	HCl	0.5	60 (140)	1	D	C	C	...	...	D	A
Hydrochloric acid	HCl	10	Room	...	D	D	D	...	...	D	C
Hydrochloric acid	HCl	37	Room	...	D	D	D	D	A	...	...
Hydrochloric acid	HCl	37	100 (212)	...	D	D	D	D	B	...	...
Hydrofluoric acid, anhydrous	HF	...	Room	...	B	B	B	B	A	...	...
Hydrofluoric acid	HF	1–60	Room	...	D	D	D	D	D	...	...
Hydrogen, liquid	H	...	253 (488)	...	A	A	A	A	A	...	...
Kerosene	...	...	Room	...	A	A	A	A	A	...	...
Magnesium bisulfite digester liquor	$MgHSO_3$	...	Room	...	B	B	B	B	A	...	...
Methane, liquid	CH_4	...	162 (324)	...	A	A	A	A	A	...	...
Methanol, anhydrous	CH_3OH	...	Room	...	A	A	A	A	A	...	...
Methanol, 20% water	CH_3OH/H_2O	...	Room	...	A	A	A	A	A	...	...
Nitric acid	HNO_3	0.5	Room	1.1	D	C	A	...	...	A	A
Nitric acid	HNO_3	5	Room	...	D	D	D	D	B	...	...
Nitric acid	HNO_3	...	100 (212)	...	D	D	D	D	B	...	...
Nitric acid	HNO_3	10	Room	...	D	B	C	...	...	A	A
Nitrogen, liquid	N	...	196 (385)	...	A	A	A	A	A	...	...
Oil, crude (Sand, salt water, high in sulfur)	...	...	Room	...	C	C	C	C	A	...	...
Oxalic acid	$(COOH)_2{\cdot}2H_2O$	5	Room	1	A-B	A	A	...	...	A	A
Oxalic acid	$(COOH)_2{\cdot}2H_2O$	5	60 (140)	1	B-C	A	...	...	...	B	A
Oxygen, liquid	O	...	183 (361)	...	A	A	A	A	A	...	...
Perchloric acid	$HClO_4$	0.5	Room	1.3	C-D	A	C	...	...	D	...
Perchloric acid	$HClO_4$	0.5	60 (140)	1.3		D	A	D	...	D	D
Phosphoric acid	H_3PO_4	5	Room	1.2	D	B	C	...	...	A	A
Phosphoric acid	H_3PO_4	85	Room	...	D	C	C	D	A	...	...
Crude phthalic acid and anhydride	C_6H_4-1,2 $(COOH)_2$/ C_6H_4-1,2 $(CO)_2O$	...	250–280 (480–535)	...	C	C	B	C	A	...	...
Sodium carbonate	Na_2CO_3	5	Room	12	A	A	A	...	...	A	A
Sodium carbonate	Na_2CO_3	5	60 (140)	12	A	A	A	...	...	A	A
Sodium chloride	NaCl	3	Room	7	A-B	A	A	...	...	A	A
Sodium chloride	NaCl	3	60 (140)	7	A-B	A	A	...	...	A	A
Sodium cyanide	NaCN	10	Room	...	D	D	D	D	A	...	...
Sodium hydrogen sulfate	$NaHSO_4$	5	Room	1.2	C-D	A	A-B	...	...	D	A
Sodium hydrogen sulfate	$NaHSO_4$	5	60 (140)	1.2	D	C	C-D	...	...	D	A
Sodium hydroxide	NaOH	5	Room	14	A	A	A	...	...	A	A
Sodium hydroxide	NaOH	5	60 (140)	14	B	A	A	...	...	A	A
Sodium hydroxide	NaOH	40	Room	16	A	A	A	...	...	A	A
Sodium hydroxide	NaOH	40	60 (140)	16	A	A	A	...	...	A	A
Steam, superheated	H_2O	...	600 (1110)	...	A	A	A	A	A	...	...
Sulfuric acid	H_2SO_4	0.5	Room	1.2	C-D	A	B-C	...	...	C	A
Sulfuric acid	H_2SO_4	0.5	60 (140)	1.2	D	D	D	...	...	D	A

(a) A, highly resistant, negligible attack; B, resistant, light attack; C, poor resistance, medium attack; D, not resistant, not suitable. This table should be used only as a guide. Many factors, such as temperature variations, changes in chemical environment, purity of solutions, and stress or loading conditions, may invalidate these recommendations. Tests under operating conditions should be made. (b) Results were obtained under laboratory conditions in pure solutions and are classified with reference to corrosion resistance only. (c) Coupled to brass.

(Continued)

Table 24 (continued)

					Type of cemented carbide/corrosion resistance(a)					AISI stainless steels(b)	
Medium	Chemical designation	Concentration, %	Temperature, °C (°F)	pH	WC-Co	TiC-NiMo	WC-Ni	WC-CoCr	WC-TaC-Co	Type 302	Type 316
Sulfuric acid	H_2SO_4	5	Room	...	C	B	C	C	A	...	...
Sulfuric acid	H_2SO_4	5	100 (212)	...	D	C	C	D	A	...	...
Sulfuric acid	H_2SO_4	10	Room	0	D	D	B	...	...	D	A
Sulfuric acid	H_2SO_4	10	60 (140)	0	D	D	...	...	...	D	D
Sulfur, liquid	S	100	130 (265)	...	A	A	...	...	...	...	A
Water, boiler feed	H_2O	...	66 (150)	...	B	C	A	A	A	...	...
Water, fresh, distilled, purified	H_2O	...	Room	...	A	A	A	A	A	...	...
Water, tap	H_2O	...	Room	...	B	A	B	B	A	...	...
Water, sea	...	...	Room	...	B	B	B	...	A	...	...

(a) A, highly resistant, negligible attack; B, resistant, light attack; C, poor resistance, medium attack; D, not resistant, not suitable. This table should be used only as a guide. Many factors, such as temperature variations, changes in chemical environment, purity of solutions, and stress or loading conditions, may invalidate these recommendations. Tests under operating conditions should be made. (b) Results were obtained under laboratory conditions in pure solutions and are classified with reference to corrosion resistance only. (c) Coupled to brass.

Metallic Glasses

Frequently called amorphous metals and glassy metal systems, metallic glasses have recently been studied extensively for their corrosion resistance, along with a number of other qualities. They are also interesting as a tool for exploring the influence of atomic structure and chemical composition on the corrosion process. They contain none of the classic crystalline or chemical defects found in crystalline solids, such as grain boundaries and second-phase particles, and they are structurally homogeneous.

Although the temperature decrease required by metallic glasses for quenching from the liquid to the solid state is not large, the rate of heat extraction is very high and requires at least one dimension of the resulting alloy to be very thin. Because of this requirement, glassy metals produced by liquid quenching are typically in the form of ribbons, wire, and filaments. Obvious and potential areas of application would seem to be corrosion-resistant coatings and barriers. In certain applications, a thin, highly corrosion-resistant coating may be sufficient, thereby permitting the use of less expensive base materials.

Corrosion Resistance

Some glassy metals exhibit extremely good corrosion resistance due to several factors. Metallic glasses are free from such defects as grain boundaries and second-phase particles that are present in crystalline metals. Corrosion often occurs preferentially at such sites; therefore, glassy metals may be expected to exhibit better corrosion resistance than crystalline alloys. The galvanic corrosion associated with chemical inhomogeneities, such as second-phase particles, is also impossible in glassy metals. In addition, the passive films responsible for corrosion resistance in crystalline alloys also play a role in glassy metal corrosion. Thus, the effect of the amorphous structure, chemical homogeneity, and unique chemical composition on the formation and stability of the passive film must also be considered.

Early research into metallic glasses tended to concentrate on iron-base metal-metalloid glasses, but recently the range of study has widened to include many alloy systems. Results with nickel-, titanium-, copper-, and cobalt-base alloy systems, among others, have been reported in the literature. The effect of metalloid additions on corrosion behavior is reasonably well characterized, and theories have been proposed to explain the beneficial effect of phosphorus on corrosion. The influence on corrosion behavior on a wide variety of elemental additions has been evaluated, and many such additions increase corrosion resistance. Those with the strongest effect are the classic film formers such as chromium, titanium, and molybdenum.

Corrosion Behavior

Glassy alloys can be grouped into two major categories with intrinsically different corrosion behaviors. The first group includes the transition metal/metal binary alloy systems, such as Cu-Zr, Ni-Ti, W-Si, and Ni-Nb. The second class consists of transition metal/metalloid alloys. These alloys are usually iron-, nickel-, or cobalt-base systems. They may contain film formers, and they normally contain approximately 20 at.% phosphorus, bismuth, silicon, and/or carbon as the metalloid component. For the most part, descriptions of these two types of corrosion behavior are detailed laboratory results and have little direct relationship with actual corrosion conditions.

Localized Behavior

The ability to resist localized corrosion is one of the most percent of chromium very effectively resist pitting in chloride-containing solutions. Polarization curves of glassy alloys obtained in $1N$ NaCl do not show a characteristic pitting potential, rather they exhibit stable passivity until the onset of transpassivity. In addition, results of a study with $Fe_{25}Ni_{40}Cr_{15}P_{16}B_4$ showed that the passive range of $1N$ H_2SO_4 plus $0.1N$ NaCl is not interrupted by pitting, but extends to transpassivity.

In another study, increasing the chromium content from 0 to 16 at.% in a series of Fe-Ni-Cr-P-B alloy systems facilitated passivation in acidified $1N$ NaCl, but pitting was not observed on any alloy polarized below the transpassivity potential region. Polarization at transpassive potentials caused

numerous pits to form that penetrated the filament and were noncrystallographic in shape.

Chromium

Chromium was shown to be very effective in conferring pitting resistance, such as for the glassy alloys Fe-Cr_x-B_{13}-C_7 and Fe-Cr_x-B_{13}-Si_7 in 3% NaCl. With chromium levels of 2 and 5 at.%, both alloy types pitted at potentials slightly anodic to the free corrosion potential of about -0.6 V (saturated calomel electrode, SCE). The addition of 8 at.% Cr extended the pitting resistance to about 1 V(SCE), which is an extremely aggressive condition for alloys containing such a low level of chromium. By contrast, type 304 stainless steel contains about 18 wt.% Cr, yet its pitting potential is several hundred millivolts less positive than that of these glassy alloys.

Molybdenum

Molybdenum benefits the pitting resistance of glassy alloys and crystalline steels. The addition of molybdenum to glassy Fe-$Mo_xP_{13}C_7$ alloys suppressed pitting and decreased the critical current density for passivation and the passive current density. As little as 4 at.% Mo prevented pitting in 1*N* HCl, and small additions of molybdenum were more effective than chromium in decreasing corrosion rates. Molybdenum has been shown to facilitate the formation of a passive hydrated chromium or iron oxy-hydroxide film through its enrichment in the corrosion product layer during active dissolution. The enrichment assists the accumulation of the passivating species in the film by lowering the dissolution rate of the species; the molybdenum-rich product subsequently dissolves and thus leaves little molybdenum behind in the film.

Other Alloying Elements

Titanium, tantalum, molybdenum, and tungsten were incorporated by high-rate sputter deposition into alloys of the general composition T_1-T_2, where T_1 = titanium, tantalum, molybdenum, or tungsten, and T_2 = rhenium, iron, cobalt, nickel, or copper. Tungsten-iron and titanium-copper resisted pitting corrosion up to 2.5 V(SCE) in chloride solutions of pH 1 and 7. Addition of tungsten to Fe-$W_xP_{13}C_7$ increased the critical pitting potential to above 2 V(SCE) at x = 6 at.%, but x = 10 at.% caused transpassive dissolution at 1 V(SCE).

Stress-Corrosion Cracking/ Hydrogen Embrittlement

The environmentally induced fracture of glassy alloys, namely stress-corrosion cracking and hydrogen embrittlement in relation to metallic glasses, are beyond the scope of this brief introduction. These topics are detailed in *Metals Handbook*, Vol 13, 9th edition, p 868-869.

Part II

Corrosion Media

Acetaldehyde

Acetaldehyde, CH_3CHO, also known as ethanal or acetic aldehyde, is a colorless flammable liquid that boils at 21 °C. Although used in the manufacturing of dyes and plastics, it is mainly used to manufacture acetic acid. Acetaldehyde is produced commercially by the hydration of acetylene and by the catalytic oxidation of ethyl alcohol.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests, aluminum alloy 1100 was resistant to aqueous solutions of 0.1 to 100% acetaldehyde. Aluminum alloy tubing, heat exchangers, stills, tankage, and shipping drums have been used for the production and storage of acetaldehyde.

Corrosion Behavior of Various Metals and Alloys in Acetaldehyde

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	All	...	...	...	Poor	119
Platinum	P04995	...	...	Pure	200-400 (390-750)	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	200-400 (390-750)	...	0.05 (2) max	...	10
Refractory metals and alloys									
Titanium	...	...	...	75	149 (300)	...	0.001 (0.04)	...	90
Titanium	...	...	...	100	149 (300)	...	...	Resistant	90
Zr702	R60702	...	...	100	Boiling	...	0.05 (2) max	...	15
Stainless steels									
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	61 (142)	414 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14.3% acetic acid, 0.3% formic acid, water remainder	70	118 (245)	169 d	0.1 (4.6)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 8% acetic acid, 3% low boilers, water remainder	70	104 (220)	100 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 12% acetic acid, 3% low boilers, water remainder	50	92 (198)	246 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 10% acetic acid, 3% low boilers, water remainder	50	92 (198)	81 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14.5% acetic acid, 15% water, 0.5% formic acid	70	99-102 (210-215)	84.5 d	0.003 (0.1)	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	61 (142)	414 d	0.003 (0.1)	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Water remainder	97-98	66 (150)	294 d	Resistant	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 10% acetic acid, 3% low boilers, water remainder	50	92 (198)	81 d	Resistant	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 12% acetic acid, 3% low boilers, water remainder	50	92 (198)	246 d	Resistant	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetaldehyde (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 8% acetic acid, 3% low boilers,water remainder	70	104 (220)	100 d	0.003 (0.1)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14.3% acetic acid,0.3% formic acid, water remainder	70	118 (245)	169 d	0.018 (0.7)	...	89
317	S31700	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Water remainder	97-98	66 (150)	294 d	0.003 (0.1) max	...	89
AM-363	S36300	...	...	Pure	Room	...	...	Resistant	120

Acetic Acid

Acetic acid, CH_3COOH, also known as ethanoic acid or vinegar acid, is a clear, colorless liquid or crystalline mass with a pungent odor, a melting point of 16.7 °C, and a boiling point of 118.1 °C. It is miscible with water, alcohol, and ether, and it crystallizes in deliquescent needles.

Acetic acid, as well as its derivatives, is produced in large quantities. It is the most important organic acid and is frequently encountered as a contaminant in other organic chemical processes. Acetic acid is classified as a weak acid, but the effective acidity in aqueous streams increases rapidly with concentration.

In addition to being the active ingredient in vinegar, acetic acid is required in the production of synthetic resins and fibers, pharmaceuticals, photographic chemicals, flavorants, and bleaching and etching compounds. It is used as an active raw and intermediate material for various organic syntheses and as a solvent for organic substances.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum exhibits good resistance to nearly all concentrations of acetic acid at room temperature and has been used extensively for storage and shipment. It is fairly resistant to 97 and 99% CH_3COOH to the boiling point, but is attacked very rapidly in concentrations near 100% or containing excess $(CH_3CO)_2O$. Aluminum again becomes resistant to pure $(CH_3CO)_2O$, although it causes contamination of the anhydride due to formation of a white crystalline solid, aluminum triacetate, $Al(C_2H_3O_2)_3$, which precipitates in the liquid.

The corrosion resistance of aluminum in acetic acid is strongly affected by contaminants. Aluminum can corrode in almost any concentration of CH_3COOH at any temperature if the acid is contaminated with the proper species.

Cast Irons. Unalloyed cast iron can be used to handle concentrated acetic acid, but it is attacked by more dilute solutions. Austenitic nickel cast irons and high-chromium cast irons exhibit adequate resistance to CH_3COOH. High-silicon cast irons show excellent resistance to most organic acids in all temperature and concentration ranges.

Carbon and Alloy Steels. Steel is attacked quite rapidly by all concentrations of acetic acid, even at room temperature. Glacial CH_3COOH at room temperature is less aggressive than aqueous solutions of the acid, but still gives a rate of attack of 0.8 to 1.3 mm/yr (30 to 50 mils/yr). Therefore, steel is normally unacceptable for use in CH_3COOH service.

Stainless Steels. The chromium stainless steels of the 400 series occasionally exhibit low corrosion rates in laboratory tests in dilute acetic acid. However, because field experience with these materials indicates high corrosion rates and pitting attack, they are rarely used for CH_3COOH production equipment. Type 304 stainless steel is the lowest grade commonly used. Exceptions include the high-purity ferritic stainless steels, which show good resistance.

Type 304 stainless steel finds wide application in dilute CH_3COOH and in the shipment and storage of concentrated CH_3COOH. Data show that glacial CH_3COOH can be handled in type 304 stainless steel to a temperature of about 80 °C (175 °F) and that type 304 has been satisfactory for lower concentrations to the boiling point of the acid. At temperatures above 60 °C (140 °F), use of the low-carbon type 340L is advisable for welded construction to prevent intergranular attack of heat-affected zones.

Type 316 stainless steel is the alloy most commonly used in CH_3COOH processing equipment. It will resist glacial acid to temperatures above the atmospheric boiling point. As with type 304 stainless steel, the low-carbon grade (type 316L) is required for the higher temperature application. Higher alloys, such as 20Cb-3 and Incoloy 825, show better resistance to CH_3COOH than type 316 stainless steel.

Acetic anhydride was produced as a coproduct in the old acetaldehyde oxidation process for acetic acid and is found in other acid streams. When CH_3COOH is truly anhydrous or contains small quantities of $(CH_3CO)_2O$, the rate of attack on type 316 stainless steel increases dra-

matically. Experience has shown that the introduction of a few tenths of a percent of water will reduce the corrosion.

Impurities present in the manufacture of acetic acid, such as acetaldehyde, formic acid, chlorides, and propionic acid, are expected to increase the attack of stainless steels. Contamination with chloride can cause pitting, rapid stress-corrosion cracking, and accelerated corrosion of type 316 stainless steel. Up to 20 ppm of chloride can be tolerated, but higher concentrations are likely to cause rapid equipment failure.

Transferring heat through a metal wall, as in heat exchangers, can drastically alter the corrosion characteristics of the metal.

Cemented Carbides. Many cemented carbide compositions can be used in acetic acid with little corrosion.

Copper. Copper and its alloys, except those with high zinc contents (>15% Zn), show good resistance to all concentrations of acetic acid up to and even above the atmospheric boiling temperature in the absence of oxygen or other oxidants. Copper was used almost exclusively to handle CH_3COOH until the advent of the stainless steels, but type 316 stainless steel and higher alloys are currently used.

Copper and copper alloys are used successfully in commercial processes involving exposure to CH_3COOH and related chemical compounds or in the manufacture of this acid. One plant kept records concerning the corrosion rate of C11000 used in two different CH_3COOH still systems. One still operated at 115 to 140 °C (240 to 285 °F) and handled a solution containing 50% CH_3COOH and about 50% $(CH_3CO)_2O$, with some esters also present. After operating for 663 h, the kettle showed an average penetration rate of 210 μm/yr (8.4 mils/yr). The rate was lower (60 μm/yr, or 2.4 mils/yr) for the bottom column and was lower yet (30 μm/yr, or 1.2 mils/yr) for the middle and top columns. A second still operating at 60 to 140 °C (140 to 285 °F) contained a 70% solution of CH_3COOH, the remainder being anhydride, esters, and ketones. After 1464 h, the kettle showed a corrosion rate of 120 μm/yr (4.8 mils/yr). The rate was only 30 μm/yr (1.2 mils/yr) for the middle and top columns.

In another field test, C11000 and C65500 coupons were placed in an acetic acid storage tank at ambient temperature. The stored solution contained 27% CH_3COOH, 1% butyl acetate, 70% H_2O, and small amounts of acetates, aldehydes, and other acids. During the 3984-h exposure, the specimens were immersed in the liquid phase 80% of the time and were in the vapor phase 20% of the time. The C11000 specimens showed a corrosion rate of 38 to 53 μm/yr (1.5 to 2.1 mils/yr); the C65500 specimens, 30 to 45 μm/yr (1.2 to 1.8 mils/yr).

In laboratory tests at room temperature, C61300 and C62300 exhibited typical corrosion rates of 65 to 80 μm/yr (2.5 to 3.2 mils/yr) in 10 to 40% CH_3COOH. The copper-aluminum alloys are suitable for use in CH_3COOH and the range of aliphatic and aromatic organic acids. The addition of chlorine atoms to the organic molecule will not increase the tendency toward pitting or crevice corrosion. Alloy C61300 is extensively used for pressure and valve castings.

The absence of oxidizing agents is essential for copper to resist attack by CH_3COOH and other organic acids. Copper is nearly immune to attack by pure, uncontaminated CH_3COOH, yet slight contamination with air through storage under an air atmosphere or by entry of air through a pump seal can increase the rate of attack in a copper column to hundreds of mils per year. One set of laboratory tests at room temperature in 50% CH_3COOH showed corrosion rates of 1.8 mm/yr (71.5 mils/yr) when the solution was sparged with oxygen, but only 0.08 mm/yr (3.1 mils/yr) when the solution was nitrogen sparged.

The addition of nickel to copper moderates the effect of oxidants. Tests in boiling 50% acetic acid sparged with air for 120 h gave rates of 7.9 mm/yr (310 mils/yr) for copper, 4.8 mm/yr (188 mils/yr) for copper alloy C71500 (copper-nickel, 30%), and 2.1 mm/yr (84 mils/yr) for copper containing 67% Ni. Similar reductions with increasing nickel content were noted when Fe^{3+} ion was added to the solution; however, rates still remained quite high.

Aluminum bronzes are generally suitable for service in CH_3COOH.

Lead. Lead has very limited resistance to acetic acid. It has been used to store glacial CH_3COOH where temperature, degree of aeration, and velocity are low, but dilute CH_3COOH, even at room temperature, attacks lead at rates exceeding 1.3 mm/yr (50 mils/yr). These rates increase rapidly with increasing aeration and velocity. However, although acetic acid rapidly attacks lead when dilute, it has little effect at strengths of 52 to 70%.

Nickel. Tests have shown that aeration and oxidizing ions have detrimental effects on the resistance of Nickel 200 and Monel 400 to corrosion by acetic acid, especially in dilute concentrations. No deliberate aeration or deaeration was done in these tests. The corrosion rates of all the alloys are quite low in these environments. Even though pure acetic acid is not very aggressive, the addition of contaminants can increase the corrosion rates.

Hastelloy alloys C-276 and B resist acetic acid solutions at all concentrations and normal temperatures. These materials are sometimes used where the acid is used in conjunction with inorganic acids and salts that limit the use of stainless steels or copper alloys. Hastelloy B is used under reducing conditions, such as with combinations of CH_3COOH and H_2SO_4, whereas Hastelloy C-276 is commonly used in highly oxidizing CH_3COOH solutions.

Silver. Silver has been frequently used in Europe to handle acetic acid, and it is quite resistant to all concentrations at normal temperatures. Because of cost, silver has been used very little in the United States.

Tin. Even small additions of lead to tin impair the retention of its bright reflective surface in common atmospheres. With increasing lead content, the appearance of soldered joints becomes increasingly dull, like that of lead. However, destructive corrosion (except effects from flux residues) is highly unusual.

On rare occasions, within enclosed spaces, condensed pure water may extract lead, but more common causes of trouble are volatile organic acids. Acetic acid vapors from wood or insulating materials, and formic acid (HCOOH) or other acids that may come from insulating materials, may attack lead-containing solders to produce a white incrustation and cause serious destruction of metal.

Titanium. Titanium resists all concentrations of acetic acid up to the atmospheric boiling point. Electrochemical studies in CH_3COOH solutions suggest that it is possible to attack titanium in anhydrous acetic acid, but titanium has been used very successfully. The high-strength titanium alloys should not be used, because of their susceptibility to stress-corrosion cracking.

Zirconium. Zirconium resists corrosion in acetic acid and acetic anhydride.

Abstract: The organic acids constitute an important group of chemicals that are handled industrially in large volume. The corrosion characteristics and materials (Al 1100 and 5086, Cu-Ni, steel and Ti) used to manufacture and store formic, acetic and propionic acid are presented in detail.

Corrosion Behavior of Various Metals and Alloys in Acetic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	0-100% solution	...	0-118 (32-244)	...	Questionable	...	92
Aluminum-manganese alloys	...	...	0-100% solution	...	0-118 (32-244)	...	Questionable	...	92
Carbon and steel alloys									
16Ni, 8Cr, 5Si, 1Cu	...	...	Glacial	...	80	96 h	0.03 (1.0)	...	206
16Ni, 8Cr, 5Si, 1Cu, 1Mo	...	...	Glacial	...	...	96 h	0.03 (1.0)	...	206
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Generally suitable, crude	...	...	...	0.05 (2) max	...	93
Ampco 8, aluminum bronze	C61300	...	Generally suitable. Conditions such as aeration or temperature could restrict use. Vapors	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
C11000	C11000	...	...	Pure	...	2448 h	0.005 (0.2)	...	70
C11000	C11000	...	Plus an acetic anhydride acetone mixture	...	110-140 (230-285)	1115 h	0.483 (19.0)	...	70
C11000	C11000	...	Plus an acetic anhydride acetone mixture	...	110-140 (230-285)	2952 h	0.066-0.07 (2.6-2.8)	...	70
C11000	C11000	Annealed	Test specimens were exposed in cycle feed lines	90	30-50 (86-122)	672 h	0.06 (2.4)	...	69
C11000	C11000	Annealed	Test specimens were exposed in cycle feed lines	90	30-50 (86-122)	816 h	0.03 (1.2)	...	69
C11000	C11000	Cold worked	Test specimens were exposed in cycle feed lines	90	30-50 (86-122)	672 h	0.09 (3.6)	...	69
C11000	C11000	Cold worked	Test specimens were exposed in cycle feed lines	90	30-50 (86-122)	792 h	0.09 (3.6)	...	69
C11000	C11000	...	Test specimens were exposed in the acetic acid recovery column, where concentration of the acetic acid was 45% max	45	...	1038 h	0.03 (1.2) max	...	69
C11000	C11000	...	Test specimens were exposed to crude by-product acetic acid (approx. 25% concentration) in pump suction line from storage tank	25	...	432 h	0.274 (10.8)	...	69
C11000	C11000	...	Test specimens were exposed to crude by-product acetic acid (approx. 25% concentration) in pump suction line from storage tank	25	...	792 h	0.152 (6.0)	...	69
C11000	C11000	...	With 5% acetic anhydride, liquid phase	95	120 (250)	865 h	0.097-0.116 (3.8-4.4)	...	70
C11000	C11000	...	With 5% acetic anhydride, vapor phase	95	120 (250)	865 h	0.102-0.104 (4.0-4.1)	...	70
C11000	C11000	...	With 50% acetic anhydride	50	150 (300)	2448 h	0.084-0.090 (3.3-3.6)	...	70
C11000	C11000	...	With an equal part acetic anhydride	...	130-145 (265-295)	1115 h	0.12-0.533 (4.7-21.0)	...	70
C65500	C65500	...	Plus an acetic anhydride acetone mixture	...	110-140 (230-285)	1115 h	0.213 (8.4)	...	70
C65500	C65500	...	Plus an acetic anhydride acetone mixture	...	110-140 (230-285)	2952 h	0.07-0.09 (2.7-3.6)	...	70
C65500	C65500	...	Test specimens were exposed in the acetic acid recovery column, where concentration of the acetic acid was 45% max	45	...	1038 h	0.03 (1.2) max	...	69

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
C65500	C65500	...	With an equal part acetic anhydride	...	130-145 (265-295)	1115 h	0.116-0.236 (4.6-9.3)	...	70
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Copper	...	Brazed with BCuP-5 filler metal	Test specimens were exposed in cycle feed lines	90	...	1512 h	0.183 (7.2)	...	69
Copper	...	Brazed with BCuP-5 filler metal	Test specimens were exposed in cycle feed lines	90	...	4000 h	0.12 (4.8)	...	69
Copper	...	Brazed BAg filler metal	Test specimens were exposed in cycle feed lines	90	...	1512 h	0.183 (7.2)	...	69
Copper	...	Brazed BAg filler metal	Test specimens were exposed in cycle feed lines	90	...	4000 h	0.12 (4.8)	...	69
Copper	...	Brazed BAg filler metal	Test specimens were exposed in the acetic acid recovery column, where concentration of the acetic acid was 45% max	45	...	1038 h	0.03 (1.2) max	...	69
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	Glacial	...	100 (212)	...	0.05 (2) max	...	8
High purity lead	L50001	...	...	0.1	20 (68)	5 h	1.05 (42)	...	244
High purity lead	L50001	...	...	1.0	20 (68)	5 h	1.23 (49)	...	244
High purity lead	L50001	...	...	2.0	20 (68)	5 h	1.33 (53)	...	244
High purity lead	L50001	...	...	3.0	20 (68)	5 h	1.58 (63)	...	244
High purity lead	L50001	...	...	4.0	20 (68)	5 h	2.05 (82)	...	244
High purity lead	L50001	...	...	5.0	20 (68)	5 h	2.45 (98)	...	244
High purity lead	L50001	...	...	6.0	20 (68)	5 h	2.65 (106)	...	244
High purity lead	L50001	...	...	7.0	20 (68)	5 h	2.78 (111)	...	244
High purity lead	L50001	...	...	10.0	20 (68)	5 h	3.10 (124)	...	244
Iridium	...	...	Glacial	...	100 (212)	...	Resistant	...	29
Lead	L50045	...	Glacial	...	24 (75)	...	0.5 (20) max	...	95
Lead	L50045	...	Glacial	...	Room	...	0.25 (10) max	...	17
Magnesium	...	...	...	All	...	...	Poor	...	119
Rhodium	P05990	...	Glacial	...	100 (212)	...	Resistant	...	29
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	4
Tin	...	...	...	10	20 (68)	...	Resistant	...	94
Tin	...	...	...	10	60 (140)	...	Poor	...	94
Tin	...	...	...	10	100 (212)	...	Poor	...	94
Tin	...	...	Glacial	...	20 (68)	...	Poor	...	94
Tin	...	...	Glacial	...	60 (140)	...	Poor	...	94
Tin	...	...	Glacial	...	100 (212)	...	Poor	...	94
Tin	...	...	Hydrogen	6	...	...	.07 (3)	...	59
Tin	...	...	Oxygen	6	...	...	11 (450)	...	59
Nickel and alloys									
Alloy 625	N06625	...	...	20	Boiling	...	0.03 (1.0)	...	223

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	...	...	90	150 (302)	30 d	.004 (0.16)	...	217
Alloy 825	N08825	...	...	75	150 (302)	30 d	.20 (7.9)	...	217
Alloy 825	N08825	...	Plus 5% formic acid	85	150 (302)	30 d	.002 (0.08)	...	217
Cabot alloy No. 625	N06625	...	Average of four 24-h periods	10	Boiling	...	0.02 (0.6) max	...	67
Cabot alloy No. 625	N06625	...	Average of four 24-h periods	99	Boiling	...	0.01 (0.4)	...	67
Carpenter Pyromet Alloy 102	...	Annealed	Glacial	...	...	48 h	0.076 (3.04)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	Glacial	...	...	48 h	0.025 (1)	...	30
Carpenter Pyromet Alloy 102	...	Annealed	Plus 2% formic acid	10	...	48 h	0.152 (6.08)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	Plus 2% formic acid	10	...	48 h	0.102 (4.08)	...	30
Carpenter Pyromet Alloy 102	...	Annealed	Plus acetic anhydride (1:1)	...	...	48 h	0.686 (27.44)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	Plus acetic anhydride (1:1)	...	...	48 h	0.711 (28.44)	...	30
Hastelloy alloy B-2	N10665	...	Determined in lab tests. It is recommended that samples be tested under actual plant conditions. All test specimens were heat-treated at 1066°C (1950°F), water quenched	10	Boiling	...	0.02 (0.5) max	...	63
Hastelloy alloy B-2	N10665	...	Determined in lab tests. It is recommended that samples be tested under actual plant conditions. All test specimens were heat-treated at 1066°C (1950°F), water quenched	30	Boiling	...	0.01 (0.4)	...	63
Hastelloy alloy B-2	N10665	...	Determined in lab tests. It is recommended that samples be tested under actual plant conditions. All test specimens were heat-treated at 1066°C (1950°F), water quenched	50	Boiling	...	0.01 (0.4)	...	63
Hastelloy alloy B-2	N10665	...	Determined in lab tests. It is recommended that samples be tested under actual plant conditions. All test specimens were heat-treated at 1066°C (1950°F), water quenched	70	Boiling	...	0.01 (0.3) max	...	63
Hastelloy alloy B-2	N10665	...	Glacial. Determined in lab tests. It is recommended that samples be tested under actual plant conditions. All test specimens were heat-treated at 1066°C (1950°F), water quenched	99	Boiling	...	0.01 (0.3) max	...	63
Incoloy alloy 800	N08800	...	Plus 0.5% H_2SO_4. Solutions were prepared with reagent-grade chemical. Test specimens were cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	10	80 (176)	7 d	0.003 (0.1) max	No pitting	44
Incoloy alloy 800	N08800	...	Plus 0.5% NaCl. Solutions were prepared with reagent-grade chemical. Test specimens were cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	10	80 (176)	42 d	0.003 (0.1) max	Incipient pits after 42 d	44
Incoloy alloy 800	N08800	...	Solutions were prepared with reagent-grade chemicals. Test specimens were cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	10	80 (176)	7 d	0.003 (0.1) max	No pitting	44
Incoloy alloy 825	N08825	...	1% formic acid, 5% high boiling esters	94	127 (260)	465 d	0.018 (0.7)	...	43
Incoloy alloy 825	N08825	...	1.5 to 3.0% formic acid, 0.5% potassium permanganate, balance water	95	110-143 (230-290)	55 d	0.038 (1.5)	...	43
Incoloy alloy 825	N08825	...	1.5% formic acid, 1 to 1.5% water	96.5-98	124 (255)	262 d	0.152 (6.0)	...	43

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Incoloy alloy 825	N08825	...	2.5% formic acid, 6.0% water	91.5	110-127 (230-260)	55 d	0.079 (3.1)	...	43
Incoloy alloy 825	N08825	...	6% propionic acid, 20% butane, 5% pentane, 8% ethyl acetate, 5% methyl ethyl ketone, plus other esters and ketones	40	174 (345)	217 d	0.051 (2.0)	...	43
Incoloy alloy 825	N08825	...	Less than 0.1% water in still	99.9	107 (225)	40 d	0.005 (0.2)	...	43
Incoloy alloy 825	N08825	...	Vapors of 85% acetic acid, 10% acetic anhydride, 5% water, plus some acetone, acetonitrile, in vapor line just before condenser	85	116-135 (240-275)	875 d	0.008 (0.3)	...	43
Inconel alloy 601	N06601	...	...	10	80 (176)	7 d	0.002 (0.1) max	...	64
Inconel alloy 601	N06601	...	Plus 0.5% H_2SO_4. Average of two tests	10	80 (176)	7 d	1.161 (45.7)	...	64
Inconel alloy 601	N06601	...	Plus 0.5% NaCl. Average of two tests	10	80 (176)	30 d	0.554 (21.8)	...	64
Inconel alloy 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Inconel alloy 690	N06690	...	Plus 0.5% H_2SO_4	10	80 (176)	...	0.03 (1) max	...	57
MP35N	R30035	...	...	99	Boiling	...	0.015 (0.6)	...	23
Nickel 200	N02200	...	3200 ppm Cu^{2+} added as acetate	100	Boiling	...	0.81 (32)	...	65
Nickel 200	N02200	...	3200 ppm Cu^{2+} added as acetate	50	Boiling	...	0.71 (28)	...	65
Nickel 200	N02200	...	Aerated	30	30 (86)	...	0.084 (3.3)	...	21
Nickel 200	N02200	...	Aerated	50	30 (86)	...	0.11 (4.3)	...	21
Nickel 200	N02200	...	Aerated	99.9	116 (240)	...	0.009 (0.36)	...	21
Nickel 200	N02200	...	Air saturated	0.10	Room	...	0.25 (10)	...	44
Nickel 200	N02200	...	Air saturated	5	Room	...	1 (40)	...	44
Nickel 200	N02200	...	Air saturated	85	Room	...	10 (400)	...	44
Nickel 200	N02200	...	Air sparge	100	Boiling	...	0.025 (1)	...	50
Nickel 200	N02200	...	Air sparge	50	Boiling	...	1.6 (63)	...	50
Nickel 200	N02200	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.11 (4.5)	...	50
Nickel 200	N02200	...	No air	100	Boiling	...	0.036 (1.4)	...	50
Nickel 200	N02200	...	No air	50	Boiling	...	0.076 (3)	...	50
Nickel 200	N02200	...	Unaerated	5	116 (240)	...	0.007 (0.28)	...	21
Nickel 200	N02200	...	Unaerated	10	30 (86)	...	0.0025 (0.1)	...	21
Nickel 200	N02200	...	Unaerated	50	30 (86)	...	0.006 (0.25)	...	21
Nickel 200	N02200	...	Unaerated	99.9	30 (86)	...	0.003 (0.13)	...	21
Nickel 400	N04400	...	3200 ppm Cu^{2+} added as acetate	100	Boiling	...	2.97 (117)	...	65
Nickel 400	N04400	...	3200 ppm Cu^{2+} added as acetate	50	Boiling	...	0.9 (36)	...	65
Nickel 400	N04400	...	Aerated	10	30 (86)	...	0.008 (0.33)	...	21
Nickel 400	N04400	...	Aerated	25	30 (86)	...	0.01 (0.41)	...	21
Nickel 400	N04400	...	Aerated	50	30 (86)	...	0.019 (0.74)	...	21
Nickel 400	N04400	...	Aerated	75	30 (86)	...	0.009 (0.36)	...	21
Nickel 400	N04400	...	Aerated	99.9	30 (86)	...	0.006 (0.23)	...	21
Nickel 400	N04400	...	Aerated	99.9	116 (240)	...	0.004 (0.15)	...	21
Nickel 400	N04400	...	Air sparge	100	Boiling	...	0.05 (2)	...	50
Nickel 400	N04400	...	Air sparge	50	Boiling	...	2.1 (84)	...	50
Nickel 400	N04400	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.015 (0.6)	...	50
Nickel 400	N04400	...	No air	100	Boiling	...	0.0025 (0.1)	...	50
Nickel 400	N04400	...	No air	50	Boiling	...	0.025 (1)	...	50
Nickel 400	N04400	...	Unaerated	2	30 (86)	...	0.0008 (0.03)	...	21
Nickel 400	N04400	...	Unaerated	50	30 (86)	...	0.0025 (0.1)	...	21
Nickel 400	N04400	...	Unaerated	5	116 (240)	...	0.0008 (0.03)	...	21
Nickel 400	N04400	...	Unaerated	10	30 (86)	...	0.002 (0.08)	...	21
Nickel 400	N04400	...	Unaerated	25	30 (86)	...	0.002 (0.08)	...	21
Nickel 400	N04400	...	Unaerated	75	30 (86)	...	0.0013 (0.05)	...	21
Nickel 400	N04400	...	Unaerated	99.9	30 (86)	...	0.002 (0.08)	...	21
Nickel 600	N06600	...	Unaerated	2	30 (86)	...	0.0013 (0.05)	...	21
Nickel 600	N06600	...	Unaerated	5	116 (240)	...	0.002 (0.08)	...	21

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 600	N06600	...	Unaerated	10	30 (86)	...	0.0005 (0.02)	...	21
Nickel 625	N06625	...	Mill annealed. Based on four 24-h tests	10	Boiling	24 h	0.01-0.019	...	50
Nickel 625	N06625	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.39 (0.77)	...	50
Nickel 625	N06625	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.01 (0.4)	...	50
Nickel 825	N08825	...	Mill annealed. Based on four 24-h tests	10	Boiling	24 h	0.0152-0.016 (0.60-0.63)	...	50
Nickel alloy C	N10002	...	...	90	150 (302)	30 d	0.049 (1.93)	...	217
Nickel alloy C	N10002	...	...	75	150 (302)	30 d	.076 (3.0)	...	217
Nickel alloy C	N10002	...	Plus 5% formic acid	85	150 (302)	30 d	.073 (2.88)	...	217
Nickel B-2	N10665	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.03 (1.2)	...	50
Nickel B-2	N10665	...	Mill annealed. Based on four 24-h tests	10	Boiling	24 h	0.0112-0.013 (0.44-0.50)	...	50
Nickel C-276	N10276	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.0076 (0.3)	...	50
Nickel C-276	N10276	...	Mill annealed. Based on four 24-h tests	10	Boiling	24 h	0.011-0.011 (0.41-0.45)	...	50
Nickel C-4	N06455	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.0005 (0.02)	...	50
Nickel G	N06007	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.03 (1.2)	...	50
Nickel G	N06007	...	Mill annealed. Based on four 24-h tests	10	Boiling	24 h	0.011-0.014 (0.43-0.54)	...	50
Nickel G-2	N06975	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.005 (0.2)	...	50
Nickel G-3	N06985	...	Mill annealed. Based on four 24-h tests	99	Boiling	24 h	0.015 (0.6)	...	50
Sanicro 28	N08028	...	...	90	150 (302)	30 d	.001 (0.04)	...	217
Sanicro 28	N08028	...	...	75	150 (302)	30 d	.17 (6.7)	...	217
Sanicro 28	N08028	...	Plus 5% formic acid	85	150 (302)	30 d	.001 (0.04)	...	217
Refractory metals and alloys									
44Co-31Cr-13W	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	99	Boiling	...	Resistant	...	53
44Co-31Cr-13W	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	10	Boiling	...	0.002 (0.1)	...	53
44Co-31Cr-13W	...	...	Heat treated 4 h at 899°C (1650°F), furnace cooled; cast specimen 38 mm × 1× 25 mm ×1 ×6 mm (1.5 in.× 1 × 1 in.× 1 × 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	10	Boiling	...	0.1 (4)	...	53
44Co-31Cr-13W	...	...	Heat treated 4 h at 899°C (1650°F), furnace cooled; cast specimen 38 mm × 1× 25 mm ×1 ×6 mm (1.5 in.× 1 × 1 in.× 1 × 0.25 in.), 120-grit abrasive finish	99	Boiling	...	0.007 (0.3)	...	53
50Co-20Cr-15W-10Ni	...	...	...	10	Boiling	...	0.002 (0.1)	...	53
50Co-20Cr-15W-10Ni	...	...	...	99	Boiling	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	10	Boiling	...	0.002 (0.1)	...	53
50Co-20Cr-15W-10Ni	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	99	Boiling	...	Resistant	...	53
53Co-30Cr-4.5W	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	10	Boiling	...	0.007 (0.3)	...	53
53Co-30Cr-4.5W	...	...	Cast specimen 38 mm ×1 ×25 mm× 1 × 6 mm (1.5 in.× 1× 1 in.× 1× 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	99	Boiling	...	0.007 (0.3)	...	53

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
53Co-30Cr-4.5W	...	...	Heat treated 4 h at 899°C (1650°F), furnace cooled; cast specimen 38 mm × 1 × 25 mm × 1 × 6 mm (1.5 in. × 1 × 1 in. × 1 × 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	10	Boiling	...	0.007 (0.3)	...	53
53Co-30Cr-4.5W	...	...	Heat treated 4 h at 899°C (1650°F), furnace cooled; cast specimen 38 mm × 1 × 25 mm × 1 × 6 mm (1.5 in. × 1 × 1 in. × 1 × 0.25 in.), 120-grit abrasive finish. Average of five 24-h periods	99	Boiling	...	0.01 (0.4)	...	53
Cobalt	...	...	Static	5	25 (77)	...	0.05 (2)	...	54
Havar	R30004	...	...	99	Boiling	...	0.078 (3.1)	...	23
Haynes alloy 188	R30188	...	...	99	Boiling	...	0.005 (0.20)	...	23
Haynes alloy 21	R30021	...	...	99	Boiling	...	0.017 (0.67)	...	23
Haynes alloy 25	R30605	...	...	99	Boiling	...	0.0056 (0.22)	...	23
Haynes alloy 556	R30556	...	...	99	Boiling	...	0.005 (0.20)	...	23
Haynes alloy 6B	...	...	...	99	Boiling	...	0.0008 (0.03)	...	23
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	Room	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	Room	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	Room	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	66 (150)	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	66 (150)	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	66 (150)	24 h	Resistant	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	Boiling	24 h	0.01 (0.1) max	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	Boiling	24 h	0.01 (0.1) max	...	68
Haynes alloy No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	Boiling	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	Room	24 h	Resistant	...	68

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	Room	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	Room	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	10	Boiling	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	50	Boiling	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods. All data were obtained using corrosion specimens prepared from 12-gage, solution heat-treated sheet	99	Boiling	24 h	0.01 (0.1) max	...	68
Niobium	R04210	...	...	5-99.7	Boiling	...	Resistant	...	2
Tantalum	R05210	...	...	...	100 (212)	...	Resistant	...	42
Ti-3Al-2.5V, grade 9	...	...	...	100	Boiling	...	Resistant	...	91
Titanium	...	...	...	5-99.7	124 (255)	...	Resistant	...	90
Titanium	...	...	...	33-vapor	Boiling	...	Resistant	...	90
Titanium	...	...	...	99	Boiling	...	0.003 (0.12)	...	90
Titanium	...	...	...	65	121 (250)	...	0.003 (0.12)	...	90
Titanium	...	...	...	58	130 (266)	...	0.381 (15.24)	...	90
Titanium	...	...	...	99.7	124 (255)	...	0.003 (0.12)	...	90
Titanium	...	...	...	100	Boiling	...	Resistant	...	91
Titanium	...	...	Plus 1.5% $(CH_3CO)_2O$	Glacial	204 (399)	...	0.005 (0.2)	...	90
Titanium	...	...	Plus 106 ppm Cl	62.0	Boiling	...	0.272 (10.88)	...	90
Titanium	...	...	Plus 109 ppm Cl	31.2	Boiling	...	0.259 (10.36)	...	90
Titanium	...	...	Plus 3% $(CH_3CO)_2O$	Glacial	204 (399)	...	1.02 (40.8)	...	90
Titanium	...	...	Plus 5% HCOOH	58	Boiling	...	0.457 (18.28)	...	90
Titanium, grade 12	R53400	...	Plus 5% formic acid	58	Boiling	...	Resistant	...	33
Titanium, grade 9	...	...	...	99.7	Boiling	...	Resistant	...	33
Titanium, unalloyed	...	...	...	0-99.5	100 (212)	...	.005 (0.2) max	...	218
Zr702	R60702	...	...	5-99.5	35 95-Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	100	160 (320)	...	0.025 (1) max	...	15
Zr702	R60702	...	Glacial	99.7	Boiling	...	0.13 (5) max	...	15
Zr702	R60702	...	Plus 1% I^- + 100 ppm Fe^{3+}	99	200 (390)	...	0.025 (1) max	...	15

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zr702	R60702	...	Plus 10% CH_3OH	90	200 (390)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI	80	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI	98	150 (300)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI + 1% CH_3OH + 500 ppm (HCOOH)	80	150 (300)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI + 1000 ppm Fe added as powder	80	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI + 200 ppm Cl^-	80	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI + 200 ppm Fe^{3+}	80	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI, 1% CH_3OH, 500 ppm (HCOOH), 100 ppm Cu	80	150 (300)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% HI, 1% CH_3OH, 500 ppm (HCOOH), 100 ppm Fe	80	150 (300)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 2% I^-	98	150 (300)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 50 ppm I^-	100	160 (320)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 50 ppm I^-	100	200 (390)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 50% $(CH_3 \cdot CO)_2O$	50	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus saturated gaseous HCl and Cl_2	100	Boiling	...	5 (200) min	...	15
Zr702	R60702	...	Plus saturated gaseous HCl and Cl_2	100	40 (100)	...	0.025 (1) max	...	15
Zr705	R60705	...	...	5-99.5	35 95-Boiling	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 1% I^- + 100 ppm Fe^{3+}	99	200 (390)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI	80	100 (212)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI	98	150 (300)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI + 1% CH_3OH + 500 ppm (HCOOH)	80	150 (300)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI + 200 ppm Cl^-	80	100 (212)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI + 200 ppm Cl^-	80	100 (212)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI + 200 ppm Fe^{3+}	80	100 (212)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI, 1% CH_3 OH, 500 ppm (HCOOH), 100 ppm Cu	80	150 (300)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% HI, 1% CH_3 OH, 500 ppm (HCOOH), 100 ppm Fe	80	150 (300)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 2% I^-	98	150 (300)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 50% $(CH_3 \cdot CO)_2O$	50	Boiling	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus saturated gaseous HCl and Cl_2	100	Boiling	...	5 (200) min	...	15
Stainless steels									
18Cr-2Mo	S18200	...	...	20	Boiling	...	0.005 (0.2)	...	55
18Cr-2Mo	S18200	...	...	80	Boiling	...	0.005 (0.2)	...	55
18Cr-2Ni-12Mn	S24100	...	Test conducted in three 48-h periods	50	Boiling	48 h	0.005 (0.2)	...	47
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	10	106 (223)	51 d	0.102 (4.0)	...	66
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	24	110 (230)	51 d	0.102 (4.0)	...	66
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	83	116 (241)	51 d	0.127 (5.0)	...	66

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	87	122 (252)	51 d	0.203 (8.0)	...	66
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	98	128 (262)	51 d	0.05 (2.0)	...	66
20	J95150	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	99.5	130 (266)	51 d	0.013 (0.5)	...	66
20Cb-3	N08020	...	...	90	150 (302)	30 d	0.19 (7.5)	...	217
20Cb-3	N08020	...	...	...	...	...	.05 (2)	...	219
20Cb-3	N08020	...	Plus 15% formic acid	75	150 (302)	30 d	.75 (30)	...	217
20Cb-3	N08020	...	Plus 5% formic acid	85	150 (302)	30 d	.04 (1.58)	...	217
26Cr-1Mo	S44627	...	...	20	Boiling	...	0.0 (0.0)	...	55
26Cr-1Mo	S44627	...	...	Concentrated	Boiling	...	0.013 (0.5)	...	55
26Cr-1Mo	S44627	...	Plus 220 ppm Cl^-	Concentrated	Boiling	...	0.5 (20)	...	55
29Cr-4Mo	S44700	...	...	20	Boiling	...	0.0 (0.0)	...	55
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Good	...	253
301	S30100	...	...	100	20 (68)	...	Resistant	...	253
301	S30100	...	...	100	Boiling	...	Good	...	253
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
301	S30100	...	Plus 50% Hydrogen peroxide	10	20 (68)	...	Resistant	...	253
301	S30100	...	Plus 50% Hydrogen peroxide	10	50 (122)	...	Resistant	...	253
301	S30100	...	Plus 50% Hydrogen peroxide	10	90 (194)	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Good	...	253
302	S30200	...	...	100	20 (68)	...	Resistant	...	253
302	S30200	...	...	100	Boiling	...	Good	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	Plus 50% Hydrogen peroxide	10	20 (68)	...	Resistant	...	253
302	S30200	...	Plus 50% Hydrogen peroxide	10	50 (122)	...	Resistant	...	253
302	S30200	...	Plus 50% Hydrogen peroxide	10	90 (194)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Good	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Questionable	...	253
303	S30300	...	...	50	Boiling	...	Good	...	253
303	S30300	...	...	100	20 (68)	...	Resistant	...	253
303	S30300	...	...	100	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	100	Boiling	...	Questionable	...	253
303	S30300	...	...	100	Boiling	...	Good	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	20 (68)	...	Resistant	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	20 (68)	...	Resistant	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	50 (122)	...	Resistant	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	50 (122)	...	Resistant	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	90 (194)	...	Good	...	253
303	S30300	...	Plus 50% Hydrogen peroxide	10	90 (194)	...	Resistant	...	253
304	S30400	...	...	20	Boiling	...	0.76 (30)	...	55
304	S30400	...	...	Concentrated	Boiling	...	0.081 (3.2)	...	55
304	S30400	...	...	10	Boiling	...	Resistant	...	121
304	S30400	...	...	60	15 (60)	...	Resistant	...	121
304	S30400	...	...	60	Boiling	...	Good	...	121
304	S30400	...	...	100	21 (70)	...	Resistant	...	121
304	S30400	...	...	100	Boiling	...	Good	...	121
304	S30400	...	...	20	...	...	7.5 (300)	...	219
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Good	...	253
304	S30400	...	...	100	20 (68)	...	Resistant	...	253
304	S30400	...	...	100	Boiling	...	Good	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	Aerated	5	21 (70)	...	Resistant	...	121
304	S30400	...	Aerated	10	21 (70)	...	Resistant	...	121
304	S30400	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	83	116 (241)	51 d	1.68 (66)	...	66
304	S30400	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	87	122 (252)	51 d	1.07 (42)	...	66
304	S30400	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	98	128 (262)	51 d	0.18 (7.0)	...	66
304	S30400	...	No activation	20	Boiling	24 h	0.75 (30)	...	52
304	S30400	...	No activation	80	Boiling	24 h	...	...	52
304	S30400	...	Plus 2-10% HCOOH	30-50	106 (223)	...	Poor	...	55
304	S30400	...	Plus 220 ppm Cl^-	Concentrated	Boiling	...	6.86 (270)	...	55
304	S30400	...	Plus 50% Hydrogen peroxide	10	20 (68)	...	Resistant	...	253
304	S30400	...	Plus 50% Hydrogen peroxide	10	50 (122)	...	Resistant	...	253
304	S30400	...	Plus 50% Hydrogen peroxide	10	90 (194)	...	Resistant	...	253
304	S30400	...	Test conducted in three 48-h periods	50 wt%	Boiling	48 h	0.275 (11)	...	47
304L	S30403	...	...	90	150 (302)	30 d	4.9 (193)	...	217
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Good	...	253
304L	S30403	...	...	100	20 (68)	...	Resistant	...	253
304L	S30403	...	...	100	Boiling	...	Good	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	Plus 15% formic acid	75	150 (302)	30 d	24.2 (953)	...	217
304L	S30403	...	Plus 5% formic acid	85	150 (302)	30 d	8.2 (323)	...	217
304L	S30403	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
304L	S30403	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
304L	S30403	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Good	...	253
304LN	S30453	...	...	100	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	100	Boiling	...	Good	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
304LN	S30453	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	0.0025 (0.1)	...	51
316	S31600	...	...	20	Boiling	...	0.0076 (0.3)	...	55
316	S31600	...	...	Concentrated	Boiling	...	0.013 (0.5)	...	55
316	S31600	...	...	10	Boiling	...	Resistant	...	121
316	S31600	...	...	60	15 (60)	...	Resistant	...	121
316	S31600	...	...	60	Boiling	...	Good	...	121
316	S31600	...	...	100	21 (70)	...	Resistant	...	121
316	S31600	...	...	100	Boiling	...	Good	...	121
316	S31600	...	...	...	...	...	.05 (2)	...	219
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	100	20 (68)	...	Resistant	...	253
316	S31600	...	...	100	Boiling	...	Good	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	Aerated	5	21 (70)	...	Resistant	...	121
316	S31600	...	Aerated	10	21 (70)	...	Resistant	...	121
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	10	106 (223)	51 d	0.05 (2.0)	...	66
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	24	110 (230)	51 d	0.069 (2.7)	...	66

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	83	116 (241)	51 d	0.023 (9.0)	...	66
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	87	122 (252)	51 d	0.406 (16.0)	...	66
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	98	128 (262)	51 d	0.05 (2.0)	...	66
316	S31600	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	99.5	130 (266)	51 d	0.0076 (0.3)	...	66
316	S31600	Sensitized at 650°C (1200°F)	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	10	106 (223)	51 d	0.102 (4.0)	Intergranular	66
316	S31600	Sensitized at 650°C (1200°F)	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	83	116 (241)	51 d	0.56 (22)	Intergranular	66
316	S31600	Sensitized at 650°C (1200°F)	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	98	128 (262)	51 d	0.102 (4.0)	Intergranular	66
316	S31600	...	Glacial	...	93-110 (200-230)	...	.04 (1.5) max	...	55
316	S31600	...	Glacial. Plus 4% HCOOH	...	93-110 (200-230)	...	.08 (3.3)	...	55
316	S31600	...	No activation	20	Boiling	24 h	0.0075 (0.3)	...	52
316	S31600	...	No activation	80	Boiling	24 h	...	...	52
316	S31600	...	Plus 1.25% HCOOH	25	104 (220)	...	.04 (1.5)	...	55
316	S31600	...	Plus 2-10% HCOOH	30-50	106 (223)	...	.08-0.5 (3-20)	...	55
316	S31600	...	Plus 220 ppm Cl^-	Concentrated	Boiling	...	4.57 (180)	...	55
316	S31600	...	Plus 4% HCOOH	25	104 (220)	...	.08 (3.0)	...	55
316	S31600	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
316	S31600	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
316	S31600	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Good	...	253
316F	S31620	...	...	100	20 (68)	...	Resistant	...	253
316F	S31620	...	...	100	Boiling	...	Good	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
316F	S31620	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
316F	S31620	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	90	150 (302)	30 d	.004 (0.16)	...	217
316L	S31603	...	...	20	Boiling	...	0.01 (0.1) max	...	223
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	100	20 (68)	...	Resistant	...	253
316L	S31603	...	...	100	Boiling	...	Good	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	Mill annealed	Based on four 24-h tests	10	Boiling	24 h	0.015-0.018 (0.58-0.72)	...	50
316L	S31603	...	Plus 15% formic acid	75	150 (302)	30 d	.37 (14.6)	...	217
316L	S31603	...	Plus 5% formic acid	85	150 (302)	30 d	.005 (0.20)	...	217
316L	S31603	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
316L	S31603	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
316L	S31603	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	100	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	100	Boiling	...	Good	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
316LN	S31653	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	100	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	100	Boiling	...	Good	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
316Ti	S31635	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	10	106 (223)	51 d	0.0076 (0.3)	...	66
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	24	110 (230)	51 d	0.069 (2.7)	...	66
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration5 to 10 ppm	83	116 (241)	51 d	0.102 (4.0)	...	66

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	87	122 (252)	51 d	0.025 (1.0)	...	66
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	98	128 (262)	51 d	0.025 (1.0)	...	66
317	S31700	...	Data were obtained during processing of acetic acid containing ionized halogens; concentration of halide ions varied during period of observation; estimated range of concentration, 5 to 10 ppm	99.5	130 (266)	51 d	0.01 (0.4)	...	66
317	S31700	...	Plus 1.25% HCOOH	25	104 (220)	...	.03 (1.0) max	...	55
317	S31700	...	Plus 2-10% HCOOH	30-50	106 (223)	...	.05-0.3 (2-11)	...	55
317	S31700	...	Plus 4% HCOOH	25	104 (220)	...	.05 (2.0)	...	55
317L	S31703	...	...	60	Boiling	48 h	0.051 max	...	97
317L	S31703	...	...	90	150 (302)	30 d	.001 (0.04)	...	217
317L	S31703	...	...	10	Boiling	...	.005 (0.2)	...	219
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	100	20 (68)	...	Resistant	...	253
317L	S31703	...	...	100	Boiling	...	Good	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	Plus 15% formic acid	75	150 (302)	30 d	.28 (11.0)	...	217
317L	S31703	...	Plus 5% formic acid	85	150 (302)	30 d	.002 (0.08)	...	217
317L	S31703	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
317L	S31703	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
317L	S31703	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	100	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	100	Boiling	...	Good	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
317LN	S31725	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Good	...	253
321	S32100	...	...	100	20 (68)	...	Resistant	...	253
321	S32100	...	...	100	Boiling	...	Good	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	Plus 4% HCOOH	25	104 (220)	...	Poor	...	55
321	S32100	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
321	S32100	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	100	20 (68)	...	Resistant	...	253
329	S32900	...	...	100	Boiling	...	Good	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
329	S32900	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
329	S32900	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Good	...	253
347	S34700	...	...	100	20 (68)	...	Resistant	...	253
347	S34700	...	...	100	Boiling	...	Good	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	Plus 2-10% HCOOH	30-50	106 (223)	...	Poor	...	55
347	S34700	...	Plus 4% HCOOH	25	104 (220)	...	Poor	...	55
347	S34700	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
347	S34700	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
347	S34700	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
403	S40300	...	...	50	20 (68)	...	Questionable	...	253
403	S40300	...	...	50	Boiling	...	Poor	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
403	S40300	...	...	50	20 (68)	...	Questionable	...	253
403	S40300	...	...	50	Boiling	...	Poor	...	253
403	S40300	...	...	100	20 (68)	...	Good	...	253
403	S40300	...	...	100	Boiling	...	Poor	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Questionable	...	253
403	S40300	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
403	S40300	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
403	S40300	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
405	S40500	...	...	50	Boiling	...	Poor	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	50	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	50	20 (68)	...	Questionable	...	253
405	S40500	...	...	50	Boiling	...	Poor	...	253
405	S40500	...	...	100	20 (68)	...	Good	...	253
405	S40500	...	...	100	Boiling	...	Poor	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Questionable	...	253
405	S40500	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
405	S40500	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
405	S40500	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
409	S40900	...	...	10	Boiling	...	Questionable	...	253
409	S40900	...	...	50	20 (68)	...	Questionable	...	253
409	S40900	...	...	50	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	100	20 (68)	...	Good	...	253
409	S40900	...	...	100	Boiling	...	Poor	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Questionable	...	253
409	S40900	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
409	S40900	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
409	S40900	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
410	S41000	...	...	33	Room	...	Poor	...	121
410	S41000	...	...	10	Room	...	Resistant	...	121
410	S41000	...	...	10	Boiling	...	Poor	...	121
410	S41000	...	...	60	15 (60)	...	Poor	...	121
410	S41000	...	...	60	Boiling	...	Poor	...	121
410	S41000	...	...	100	21 (70)	...	Poor	...	121
410	S41000	...	...	100	Boiling	...	Poor	...	121
410	S41000	...	...	100	Room	...	Resistant	...	121
410	S41000	...	...	10	Boiling	...	Questionable	...	253
410	S41000	...	...	50	20 (68)	...	Questionable	...	253
410	S41000	...	...	50	Boiling	...	Poor	...	253
410	S41000	...	...	100	20 (68)	...	Good	...	253
410	S41000	...	...	100	Boiling	...	Poor	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Questionable	...	253
410	S41000	...	Aerated	5	21 (70)	...	Good	...	121
410	S41000	...	Aerated	10	21 (70)	...	Poor	...	121
410	S41000	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
410	S41000	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
410	S41000	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
410	S41000	...	Vapor	100	Room	...	Poor	...	121
410	S41000	...	Vapor	33	Room	...	Poor	...	121
416	S41600	...	...	10	Boiling	...	Questionable	...	253
416	S41600	...	...	50	20 (68)	...	Questionable	...	253
416	S41600	...	...	50	Boiling	...	Poor	...	253
416	S41600	...	...	100	20 (68)	...	Good	...	253
416	S41600	...	...	100	Boiling	...	Poor	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Questionable	...	253
416	S41600	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
416	S41600	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
416	S41600	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
420	S42000	...	...	10	Boiling	...	Questionable	...	253
420	S42000	...	...	50	20 (68)	...	Questionable	...	253
420	S42000	...	...	50	Boiling	...	Poor	...	253
420	S42000	...	...	100	20 (68)	...	Good	...	253
420	S42000	...	...	100	Boiling	...	Poor	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Questionable	...	253
420	S42000	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Good	...	253
420	S42000	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Questionable	...	253
420	S42000	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Poor	...	253
430	S43000	...	...	10	Boiling	...	Good	...	121
430	S43000	...	...	60	15 (60)	...	Questionable	...	121
430	S43000	...	...	60	Boiling	...	Questionable	...	121
430	S43000	...	...	100	21 (70)	...	Questionable	...	121
430	S43000	...	...	100	Boiling	...	Questionable	...	121
430	S43000	...	...	10	20 (68)	...	Resistant	...	253

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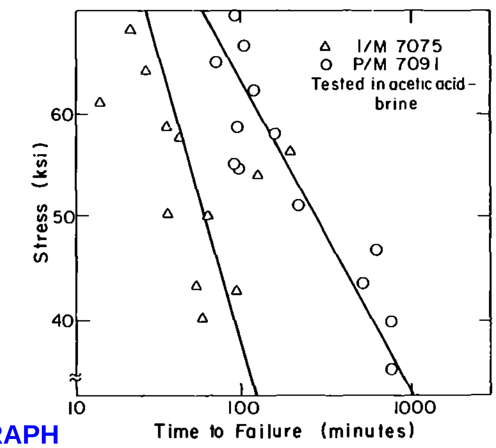
Corrosion Behavior of Various Metals and Alloys in Acetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	50	20 (68)	...	Good	...	253
430	S43000	...	...	50	Boiling	...	Questionable	...	253
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	50	20 (68)	...	Good	...	253
430	S43000	...	...	50	Boiling	...	Questionable	...	253
430	S43000	...	...	100	20 (68)	...	Resistant	...	253
430	S43000	...	...	100	Boiling	...	Questionable	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Good	...	253
430	S43000	...	Aerated	5	21 (70)	...	Resistant	...	121
430	S43000	...	Aerated	10	21 (70)	...	Good	...	121
430	S43000	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
430	S43000	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
430	S43000	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Good	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Good	...	253
434	S43400	...	...	100	20 (68)	...	Resistant	...	253
434	S43400	...	...	100	Boiling	...	Questionable	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
434	S43400	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
434	S43400	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
439	S43035	...	...	20	Boiling	...	0.09 (3.6)	...	223
444	S44400	...	...	20	Boiling	...	0.01 (0.2)	...	223
444	S44400	...	No activation	20	Boiling	24 h	0.005 (0.2)	...	52
444	S44400	...	No activation	80	Boiling	24 h	0.005 (0.2)	...	52
AL 2205	S31803	...	...	...	Boiling	...	.003 (0.1)	...	219
AL 2205	S31803	...	...	...	...	...	.003 (0.1)	...	219
AL 29-4-2	S44800	...	...	20	Boiling	...	0.01 (0.1) max	...	223
AL 29-4C	S44735	...	...	20	Boiling	...	0.01 (0.1) max	...	223
Alloy 904L	N08904	...	...	90	150 (302)	30 d	.001 (0.04)	...	217
Alloy 904L	N08904	...	...	75	150 (302)	30 d	.16 (6.3)	...	217
Alloy 904L	N08904	...	Plus 5% formic acid	85	150 (302)	30 d	.002 (0.08)	...	217
AM-363	S36300	...	...	...	Room	...	Poor	...	120
E-Brite	S44627	...	...	20	Boiling	...	0.01 (0.1) max	...	223
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253
F51	S31803	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	Boiling	...	Good	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	Plus 50% hydrogen peroxide	10	20 (68)	...	Resistant	...	253
F51	S31803	...	Plus 50% hydrogen peroxide	10	50 (122)	...	Resistant	...	253
F51	S31803	...	Plus 50% hydrogen peroxide	10	90 (194)	...	Resistant	...	253
Ferralium	S32550	...	...	10	Boiling	...	0.01 (0.4)	...	51
Ferralium 255	S32550	...	...	...	...	...	.005 (0.2)	...	219
Jessop JS700	N08700	...	...	60	Boiling	48 h	0.051 (2) max	...	97
Jessop JS700	N08700	...	Anhydride (1:1)	...	Boiling	48 h	0.025 (1)	...	97



LIVE GRAPH
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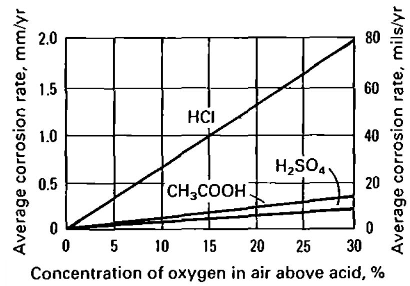
Iron- and aluminum-base P/M alloys. Stress vs. time to failure. Curves for unnotched specimens of conventional alloy 7075 and powder alloy 7091 at the same stress level in acetic acid brine. Source: P.C. Searson and R.M. Latanison, "The Corrosion and Oxidation Resistance of Iron- and Aluminum-Based Powder Metallurgical Alloys," *Corrosion Science*, Vol 25, 1985, 958.



LIVE GRAPH
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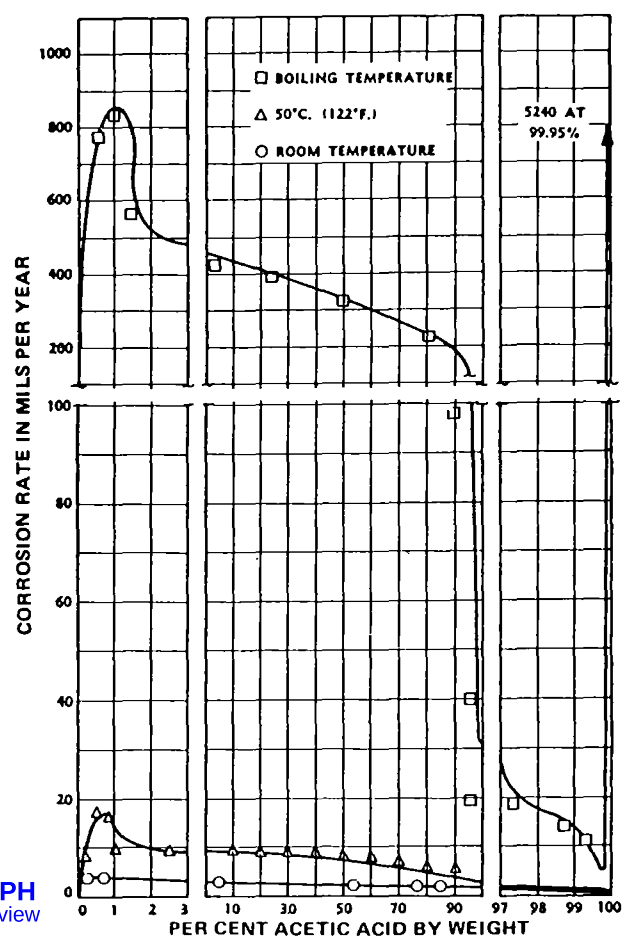
Copper. Effect of oxygen on corrosion rates for copper in 1.2*N* solutions of nonoxidizing acids. Specimens are immersed for 24 h at 24 °C (75 °F). Oxygen content of the solutions varied from test to test, depending on the concentration of oxygen in the atmosphere above the solutions. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 627.



LIVE GRAPH
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Alluminum alloys. Effect of concentration and temperature on the resistance of alloy 1100 in acetic acid. Source: *Guidlines for the Use of Aluminum with Food and Chemicals; Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 11.

Acetic Anhydride

Acetic anhydride, $(CH_3CO)_2O$, also known as ethanoric anhydride, is a liquid with a pungent odor that boils at 140 °C (284 °F). It is used for acetyration, because it forms acetic acid when combined with water.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In limited laboratory tests, aluminum alloy 3003 showed moderate (13 mils/yr) attack by acetic anhydride at 100 °C (212 °F). Mild attack at ambient temperature and at 50 °C (122 °F) was observed in other tests on aluminum alloy 1100. Acetic anhydride at the boiling point had mild action (~5 mils/yr). Acetic anhydride has been produced and handled in aluminum and aluminum alloy reaction vessels, piping, storage tanks, heat exchangers, drums, and tank cars. Valves made of aluminum alloy A356.0 have also been used.

Corrosion Behavior of Various Metals and Alloys in Acetic Anhydride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	Pure	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	...	Pure	...	...	Resistant	...	92
Aluminum-silicon alloys	...	...	...	Pure	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Test specimens were exposed in stills separating acetic acid from acetic anhydride	...	...	2448 h	0.06 (2.4)	...	69
Electrolytic copper	C11000	...	Test specimens were exposed in stills separating acetic acid from acetic anhydride. Kettle	...	...	2448 h	0.9-1.08 (36.0-43.2)	...	69
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Anhydride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silicon bronze, high	C65500	...	Test specimens were exposed in stills separating acetic acid from acetic anhydride	...	...	2448 h	0.06 (2.4)	...	69
Silicon bronze, high	C65500	...	Test specimens were exposed in stills separating acetic acid from acetic anhydride. Kettle	...	...	2448 h	0.487-0.731 (19.2-28.8)	...	69
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	0.05 (2) max	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	10
Nickel and alloys									
Alloy 825	N08825	...	Rayon processing; field or pilot test; no aeration; rapid agitation	100	134 (273)	287 d	0.003 (0.1)	...	89
Nickel 200	N02200	...	Plus 1% acetic acid in a still	99	154 (310)	...	0.005 (0.2)	...	44
Nickel 200	N02200	...	Plus 40% acetic acid in a still	60	140 (284)	...	0.015 (0.6)	...	44
Refractory metals and alloys									
Titanium	...	...	...	99-99.5	20 to boiling (70 to boiling)	...	0.13 (5) max	...	20
Titanium	...	...	...	100	21 (70)	...	0.025 (1)	...	90
Titanium	...	...	...	100	150 (302)	...	0.005 (0.02)	...	90
Titanium	...	...	...	99.5	Boiling	...	0.013 (0.52)	...	90
Zr702	R60702	...	...	99	Room to Boiling	...	0.025 (1) max	...	15
Zr705	R60705	...	...	99	Room to boiling	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	90	Boiling	...	Poor	...	121
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	Anhydride	90	21 (70)	...	Good	...	121
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 30% acetic acid	70	134-138 (273-280)	718 d	0.1 (4)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 40% acetic acid	60	130-136 (266-277)	718 d	0.13 (5)	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 50% acetic acid	50	128-139 (262-282)	718 d	0.18 (7)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation	100	137 (277)	571 d	0.3 (12)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 20% acetic acid	80	131 (268)	571 d	0.23 (9)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate agitation. Plus 40% ethylidene diacetate, 5% acetic acid, 5% solids	50	150 (302)	150 d	0.01 (0.3)	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Anhydride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	90	Boiling	...	Good	...	121
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	Anhydride	90	21 (70)	...	Good	...	121
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 50% acetic acid	50	128-139 (262-282)	718 d	0.025 (1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 40% acetic acid	60	130-136 (266-277)	718 d	0.02 (0.8)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 30% acetic acid	70	134-138 (273-280)	718 d	0.02 (0.8)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 20% acetic acid	80	131 (268)	571 d	0.015 (0.6)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation	100	137 (277)	571 d	0.13 (5)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate agitation. Plus 40% ethylidene diacetate, 5% acetic acid,5% solid	50	150 (302)	150 d	0.005 (0.2)	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	134 (273)	287 d	0.003 (0.1)	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate agitation. Plus 40% ethylidene diacetate, 5% acetic acid,5% solids	50	150 (302)	150 d	0.003 (0.1)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 50% acetic acid	50	128-139 (262-282)	718 d	0.018 (0.7)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 40% acetic acid	60	130-136 (266-277)	718 d	0.15 (6)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 30% acetic acid	70	134-138 (273-280)	718 d	0.013 (0.5)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 20% acetic acid	80	131 (268)	571 d	0.01 (0.4)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation	100	137 (277)	571 d	0.075 (3)	...	89
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetic Anhydride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Questionable	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Questionable	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Questionable	...	253
410	S41000	...	...	90	Boiling	...	Poor	...	121
410	S41000	...	...	100	Room	...	Good	...	121
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Questionable	...	253
410	S41000	...	Anhydride	90	21 (70)	...	Questionable	...	121
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Questionable	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Questionable	...	253
430	S43000	...	...	90	Boiling	...	Poor	...	121
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Good	...	253
430	S43000	...	Anhydride	90	21 (70)	...	Questionable	...	121
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	Pure	Room	...	Good	...	120
Carpenter 20	...	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	134 (273)	287 d	0.003 (0.1)	...	89
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Acetone

Acetone, CH_3COCH_3, also known as 2-propanone and dimethyl ketone, is a colorless, volatile, flammable liquid that boils at 56 °C (133 °F). It is miscible with water and is often used as a solvent in the manufacture of lacquers and paints.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests, aluminum and aluminum-magnesium alloys have shown resistance to acetone at all temperatures. Aluminum pipes, stills, heat exchangers, and storage tanks have been used to handle acetone. Redistilled acetone was reported to have caused mild corrosion in an aluminum storage tank. Valves made of aluminum alloy 356.0 have been used in handling acetone.

Corrosion Behavior of Various Metals and Alloys in Acetone

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	Field corrosion rate, based on metal loss on the inside tube diameter near the rupture. Tube metal temperature near the point of failure was estimated based on oxide thickness measurements on the outside diameter	...	593 (1100)	...	4.3 (170)	...	71
Carbon steel	G10100	...	Field corrosion rate, based on tube thickness measurements near the return bend and the thermocouple, away from the area of failure	...	482 (900)	...	0.76-1.3 (30-50)	...	71
Carbon steel	G10100	...	Lab corrosion rate	...	482 (900)	...	1.0 (40)	...	71
Carbon steel	G10100	...	Lab corrosion rate; tube metal temperature near the point of failure was estimated based on oxide thickness measurements on the outside diameter	...	621 (1150)	...	4.8 (190)	...	71
Carbon steel	G10100	...	Lab corrosion rate; tube metal temperature near the point of failure was estimated based on oxide thickness measurements on the outside diameter	...	565 (1050)	...	2.2 (85)	...	71
Carbon steel	G10100	...	Lab corrosion rate; tube metal temperature near the point of failure was estimated based on oxide thickness measurements on the outside diameter	...	593 (1100)	...	3.2 (125)	...	71
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	10-90	24-100 (75-212)	...	0.05 (2) max	...	95
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10

(Continued)

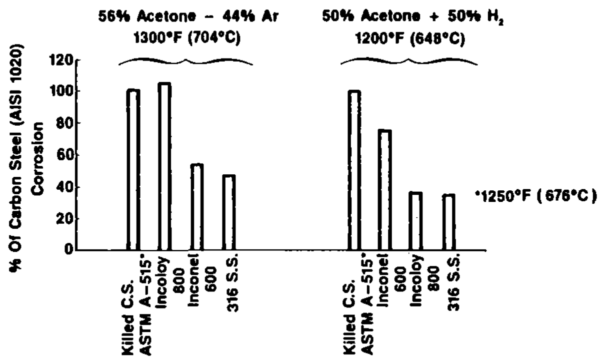
Corrosion Behavior of Various Metals and Alloys in Acetone (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Good	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field test; slight to moderate aeration; rapid agitation. Plus 38% methanol, 15% methyl acetate, 2% water, and 0.1% acetic acid	45	57 (135)	210 d	Resistant	...	89
304	S30400	...	Chemical processing; no aeration; slight to moderate agitation. Plus 30% methyl acetate, 10% acetaldehyde, pH 5.0- 6.0	60	80 (176)	210 d	0.008 (0.3)	...	89
304	S30400	...	Plastic (distillation) processing; field test; no aeration, slight to moderate agitation. Plus 60% water	40	63 (145)	59 d	0.003 (0.1) max	...	89
304	S30400	...	Rayon processing; field test; no aeration; rapid agitation. Plus mesityl oxide, dibutyl alcohol, and water	98	58 (137)	181 d	0.003 (0.1)	...	89
304	S30400	...	Rayon processing; no aeration; rapid agitation. Plus 16% metanol, 12% methyl acetate, 3% acetaldehyde, 1% ethyl acetate, 1% ethanol, and methyl-ethyl ketone	16	92 (198)	294 d	0.003 (0.1) max	...	89
304	S30400	...	Soap (solvent recovery) processing; field test; no aeration; slight to moderate agitation; with carbon over the standard maximum. Plus oleic linoleic acid remainder (still half immersed)	90	63 (145)	6 d	Resistant	...	89
304	S30400	...	Soap (solvent recovery) processing; field test; no aeration; slight to moderate agitation. Plus oleic linoleic acid remainder (still half immersed)	90	63 (145)	6 d	0.003 (0.1)	...	89
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	Chemical processing; field test; slight to moderate aeration; rapid agitation. Plus 38% methanol, 15% methyl acetate, 2% water, and 0.1% acetic acid	45	57 (135)	210 d	Resistant	...	89
316	S31600	...	Chemical processing; no aeration; slight to moderate agitation. Plus 30% methyl acetate, 10% acetaldehyde, pH 5.0- 6.0	60	80 (176)	210 d	0.01 (0.4)	...	89

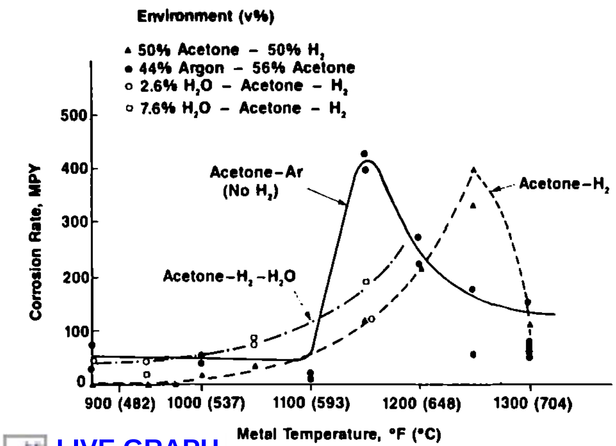
(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetone (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Plastic (distillation) processing; field test; no aeration, slight to moderate agitation. Plus 60% water	40	63 (145)	59 d	0.003 (0.1) max	...	89
316	S31600	...	Rayon processing; field test; no aeration; rapid agitation. Plus mesityl oxide, dibutyl alcohol, and water	98	58 (137)	181 d	0.003 (0.1) max	...	89
316	S31600	...	Rayon processing; no aeration; rapid agitation. Plus 16% metanol, 12% methyl acetate, 3% acetaldehyde, 1% ethyl acetate, 1% ethanol, and methyl- ethyl ketone	16	92 (198)	294 d	0.003 (0.1) max	...	89
316	S31600	...	Soap (solvent recovery) processing; field test; no aeration; slight agitation. Plus oleic linoleic acid remainder (still half immersed)	90	63 (145)	6 d	0.003 (0.1)	...	89
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Good	...	253
403	S40300	...	...	All concentrations	Boiling	...	Questionable	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Good	...	253
405	S40500	...	...	All concentrations	Boiling	...	Questionable	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Good	...	253
409	S40900	...	...	All concentrations	Boiling	...	Questionable	...	253
410	S41000	...	...	Pure	Room	...	Good	...	121
410	S41000	...	...	All concentrations	20 (68)	...	Good	...	253
410	S41000	...	...	All concentrations	Boiling	...	Questionable	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Good	...	253
416	S41600	...	...	All concentrations	Boiling	...	Questionable	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Good	...	253
420	S42000	...	...	All concentrations	Boiling	...	Questionable	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Good	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	Pure	Room	...	Resistant	...	120
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253



Carbon steel. Comparison of corrosion rates of various alloys in acetone-argon and acetone-hydrogen mixtures with carbon steel. Specimens were exposed for 3 h. Source: Z.A. Foroulis and R.J. Franco, "High Temperature Internal Corrosion of an Acetone Plant Furnace Outlet Tube: Failure Analysis and Laboratory Simulation," *Materials Performance*, Vol 25, Oct, 1985, 55.



LIVE GRAPH
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Carbon steel. Effect of temperature on corrosion of carbon steel in acetone vapors. Specimens were exposed for 3 h. Source: Z.A. Foroulis and R.J. Franco, "High Temperature Internal Corrosion of an Acetone Plant Furnace Outlet Tube: Failure Analysis and Laboratory Simulation," *Materials Performance*, Vol 25, Oct, 1985, 53.

Acetyl Chloride

Acetyl chloride, CH_3OCCl, can be prepared by treatment of acetic acid with various reagents, such as PCl_3 $SOCl_2$ or $COCl_2$. It can be prepared by chlorination of acetic anhydride in several different ways, by reaction of methyl chloride with carbon monoxide in the presence of catalysts, by reaction of ketene with HCl, or by partial hydrolysis of 1, 1, 1-trichloroethane. Acetyl chloride hydrolyzes in the presence of water to give acetic acid. It reacts with ammonia and amines to give acetamides. Reaction with alcohols gives the corresponding acetate esters. Acetyl chloride will add across unsaturated bonds in the presence of suitable catalysts to give halogenated ketones.

Corrosion Behavior of Various Metals and Alloys in Acetyl Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Good	Pitting	253
302	S30200	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
304	S30400	...	...	...	Boiling	...	Good	Pitting	253
304L	S30403	...	...	...	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	...	...	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	...	Boiling	...	Good	Pitting	253
316L	S31603	...	...	...	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	...	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Acetyl Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	...	Boiling	...	Good	Pitting	253
329	S32900	...	...	...	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	...	Boiling	...	Good	Pitting	253
403	S40300	...	...	...	Boiling	...	Questionable	Pitting	253
405	S40500	...	...	...	Boiling	...	Questionable	Pitting	253
409	S40900	...	...	...	Boiling	...	Questionable	Pitting	253
410	S41000	...	...	...	Boiling	...	Questionable	Pitting	253
416	S41600	...	...	...	Boiling	...	Questionable	Pitting	253
420	S42000	...	...	...	Boiling	...	Questionable	Pitting	253
430	S43000	...	...	...	Boiling	...	Good	Pitting	253
434	S43400	...	...	...	Boiling	...	Good	Pitting	253
F51	S31803	...	...	...	Boiling	...	Resistant	Pitting	253

Acetysalicyclic Acid

Commonly known as aspirin, $C_6H_4(COOH)CO_2CH_3$, has a melting point of 133.5 °C, is colorless, crystalline, slightly soluble in water, soluble in alcohol and ether, and also called orthoacetoxybenzoic acid. The substance is commonly used as a relief for mild forms of pain, including headache, joint, and muscle pain. Commercially available aspirin commonly is mixed with other pain relievers, so-called buffering agents, and other ingredients for the treatment of common colds.

Corrosion Behavior of Various Metals and Alloys in Acetysalicyclic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Acetysalicyclic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Adipic Acid

Adipic acid, $HOCC(CH_2)_4COOH$, is also known as hexanedioic acid and 1,4-butanedicarboxylic acid, is a colorless crystalline dicarboxylic acid. It is slightly soluble in water and has a melting point of 152 °C. It is used in the manufacture of nylon and urethane rubber.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 was mildly attacked by acid in concentrations of 20 and 50%. Aluminum is used in piping, shipping, and storing of adipic acids and its salts.

Corrosion Behavior of Various Metals and Alloys in Adipic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Titanium	...	...	...	0-67	204 (400)	...	0.05 (2) max	...	20
Titanium	...	...	...	67	240 (464)	...	Resistant	...	90
Titanium	...	...	Plus 15-20% glutaric acid + CH_3·COOH	25	199 (390)	...	Resistant	...	90
Titanium	...	...	Plus 20% glutaric acid,5% acetic acid	25	200 (390)	...	Resistant	...	20
Stainless steels									
AM-363 stainless steel	S36300	...	...	Pure	Room	...	Resistant	...	120

Aluminum Acetate

Aluminum acetate, $AL(C_2H_3O_2)_3$, is white crystals, soluble, by reaction of aluminum hydroxide and acetic acid and then crystallizing. Used as a mordant in dyeing and printing textiles, in the manufacturing of lakes, for fireproofing fabrics, for waterproofing cloth.

Corrosion Behavior of Various Metals and Alloys in Aluminum Acetate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Aluminum Acetate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Aluminum Chloride

Aluminum chloride, $AlCl_3$ or Al_2Cl_6, is a deliquescent compound found in white to colorless hexagonal crystals. Aluminum chloride reacts vigorously with water and fumes in air. It is used as a catalyst in cracking petroleum and in organic synthesis.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy containers have been used to store and transport anhydrous aluminum chloride. Aluminum alloys are corroded by moist aluminum chloride and aluminum chloride solutions. The degree of corrosion depends on the temperature and the amount of free hydrochloric acid produced by hydrolysis.

Corrosion Behavior of Various Metals and Alloys in Aluminum Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	...	...	Anhydrous	...	20 (68)	...	Resistant	...	92
Aluminum alloys	...	...	Anhydrous	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze-5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze- 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	0-10	24 (75)	...	0.5 (20) max	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	Provided oxidizing agents are not present	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	Pitting possible in stagnant solutions	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Niobium	R04210	...	...	25	Boiling	...	0.005 (0.2)	...	2
Tantalum	R05210	...	...	10	100 (212)	...	Resistant	...	42
Titanium	...	...	...	10	100 (212)	...	0.002 (0.08)	...	90
Titanium	...	...	...	10	150 (302)	...	0.03 (1.2)	...	90
Titanium	...	...	...	25	60 (140)	...	Resistant	...	90
Titanium	...	...	...	25	100 (212)	...	6.55 (262)	...	90
Titanium	...	...	Aerated	10	100 (212)	...	0.002 (0.08)	...	90
Titanium	...	...	Aerated	25	100 (212)	...	3.15 (126)	...	90
Titanium, grade 12	R53400	...	...	10	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	...	10	100 (212)	...	0.025 (1) max	...	33
Titanium, grade 7	R52400	...	...	25	100 (212)	...	0.025 (1)	...	33
Zr702	R60702	...	...	5,10,25	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	25	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	40	100 (212)	...	0.05 (2) max	...	15
Zr702	R60702	...	Aerated	5,10	60 (140)	...	0.05 (2) max	...	15
Zr705	R60705	...	...	25	Boiling	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	5	50 (122)	...	Questionable	Pitting	253
301	S30100	...	...	25	20 (68)	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	5	50 (122)	...	Questionable	Pitting	253
302	S30200	...	...	25	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	5	50 (122)	...	Questionable	Pitting	253
303	S30300	...	...	25	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	5	21 (70)	...	Poor	...	121
304	S30400	...	...	25	21 (70)	...	Poor	...	121
304	S30400	...	...	5	50 (122)	...	Questionable	Pitting	253
304	S30400	...	...	25	20 (68)	...	Poor	Pitting	253
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Aluminum chloride, water, oil	...	45-91 (113-195)	30 d	0.28 (11)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. With carbon over the standard maximum. Aluminum chloride, dust, solvent fumes (mainly benzene)	5	Room	30 d	0.018 (0.7)	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Aluminum chloride, dust, solvent fumes (mainly benzene)	5	Room	30 d	0.015 (0.6)	Moderate pitting	89
304L	S30403	...	...	5	50 (122)	...	Questionable	Pitting	253
304L	S30403	...	...	25	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	5	50 (122)	...	Questionable	Pitting	253
304LN	S30453	...	...	25	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	5	21 (70)	...	Questionable	...	121
316	S31600	...	...	25	21 (70)	...	Questionable	...	121
316	S31600	...	...	5	50 (122)	...	Good	Pitting	253
316	S31600	...	...	25	20 (68)	...	Questionable	Pitting	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Aluminum chloride, water, oil	...	45-91 (113-195)	30 d	0.1 (4)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Aluminum chloride, dust, solvent fumes (mainly benzene)	5	Room	30 d	0.01 (0.4)	Moderate pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 5% ammonium chloride, pH 2	5	26 (78)	88 d	0.004 (0.15)	Slight pitting	89
316F	S31620	...	...	5	50 (122)	...	Questionable	Pitting	253
316F	S31620	...	...	25	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	5	50 (122)	...	Good	Pitting	253
316L	S31603	...	...	25	20 (68)	...	Questionable	Pitting	253
316LN	S31653	...	...	5	50 (122)	...	Good	Pitting	253
316LN	S31653	...	...	25	20 (68)	...	Questionable	Pitting	253
316Ti	S31635	...	...	5	50 (122)	...	Good	Pitting	253
316Ti	S31635	...	...	25	20 (68)	...	Questionable	Pitting	253
317	S31700	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 5% ammonium chloride, pH 2	5	26 (78)	88 d	0.006 (0.24)	Severe pitting	89
317L	S31703	...	...	5	50 (122)	...	Good	Pitting	253
317L	S31703	...	...	25	20 (68)	...	Questionable	Pitting	253
317LN	S31725	...	...	5	50 (122)	...	Good	Pitting	253
317LN	S31725	...	...	25	20 (68)	...	Questionable	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	5	50 (122)	...	Questionable	Pitting	253
321	S32100	...	...	25	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	5	50 (122)	...	Good	Pitting	253
329	S32900	...	...	25	20 (68)	...	Questionable	Pitting	253
347	S34700	...	...	5	50 (122)	...	Questionable	Pitting	253
347	S34700	...	...	25	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	5	21 (70)	...	Poor	...	121
410	S41000	...	...	25	21 (70)	...	Poor	...	121
410	S41000	...	...	...	Room	...	Poor	...	121
430	S43000	...	...	5	21 (70)	...	Poor	...	121
430	S43000	...	...	25	21 (70)	...	Poor	...	121
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Aluminum chloride, water, oil	...	45-91 (113-195)	30 d	0.005 (5)	...	89
F51	S31803	...	...	5	50 (122)	...	Good	Pitting	253
F51	S31803	...	...	25	20 (68)	...	Questionable	Pitting	253

Aluminum Fluoride

Aluminum fluoride, AlF_3, is an anhydrous crystalline powder with a melting point of 1291 °C. Aluminum fluoride (hydrated), $AlF_3 \cdot 3\frac{1}{2}H_2O$, is a white crystalline powder that is insoluble in water.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003 and 5154 are resistant to solid aluminum fluoride at ambient temperature and 100% relative humidity in laboratory tests. Aluminum is corroded by aluminum fluoride solutions.

Corrosion Behavior of Various Metals and Alloys in Aluminum Fluoride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Zr702	R60702	...	pH 3.2	20	Room	...	1.3 (50) min	...	15
Stainless steels									
304	S30400	...	...	5	21 (70)	...	Poor	...	121
316	S31600	...	...	5	21 (70)	...	Poor	...	121
430	S43000	...	...	5	21 (70)	...	Poor	...	121
410	S41000	...	...	5	21 (70)	...	Poor	...	121
410	S41000	...	...	...	Room	...	Poor	...	121

Aluminum Hydroxide

Aluminum hydroxide, $Al(OH)_3$, also known as aluminum trihydroxide, aluminum trihydrate, aluminum hydrate, hydrated alumina, and hydrated aluminum oxide, is a white to whitish-yellow water-insoluble powder with a specific gravity of 2.42. It has a melting point of 155 °C. Aluminum hydroxide is used as a base for pigments, as a water repellent in textile coatings, and as an antacid in medicine. Aluminum hydroxide is soluble in hydrochloric or sulfuric acids or in sodium hydroxide.

Corrosion Behavior of Various Metals and Alloys in Aluminum Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Stainless steels									
AM-363	S36300	...	...	...	Room	...	Resistant	...	120

Aluminum Nitrate

Aluminum nitrate, $Al(NO_3)_3 \cdot 9H_2O$, is colorless, hygroscopic, thombic crystals that are soluble in water, alcohol and acetone, that decompose at 150 °C and has a melting point of 73.5 °C. It is made by dissolving aluminum hydroxide in nitric acid, and is used as a mordant in dyeing.

Corrosion Behavior of Various Metals and Alloys in Aluminum Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Aluminum Sulfate

Aluminum sulfate, $Al_2(SO_4)_3$, is a colorless salt composed of monoclinic crystals with a specific gravity of 2.71. It is used in manufacturing dyes, paint, and varnish removers. It decomposes with the application of heat and it is water soluble.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003 and 5154 under laboratory conditions of ambient temperature and 100% relative humidity were resistant to solid aluminum sulfate. Aqueous solutions of 0.1 to 25% aluminum sulfate showed a mild attack on aluminum alloy 1100 during laboratory tests. The paper industry has used aluminum piping for aluminum sulfate solutions. Valves of aluminum alloy 356.0 have also been used for aluminum sulfate solutions.

Corrosion Behavior of Various Metals and Alloys in Aluminum Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	...	...	Solution	...	...	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Generally suitable	...	...	...	0.05 (2) max	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 5% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red Brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Iridium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Magnesium alloy AZ61A	M11610	...	Specimen size, 75 × 25 × 1.5 mm (3 × 1 × 0.06 in.); surface preparation, HNO_3 pickling; volume of testing solution, 100 ml. Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	90 (2.3)	...	12
Palladium	P03980	...	...	100 g/L	Room	...	Resistant	...	17
Palladium	P03980	...	...	100 g/L	100 (212)	...	Resistant	...	17
Platinum	P04995	...	...	100 g/L	(212) Room - 100	...	Resistant	...	5
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Rhodium	P05990	...	...	100 g/L	100 (212)	...	Resistant	...	29
Ruthenium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Ruthenium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	7 d	0.003 (0.1) max	No pitting	44
Inconel 601	N06601	...	...	5	80 (176)	7 d	0.002 (0.1) max	...	64
Inconel 690	N06690	...	...	5	80 (176)	...	0.03 (1) max	...	57
Monel 400	N04400	...	In evaporator concentrating solution	To 57	115 (240)	44 d	0.408 (16.3)	...	79
Monel 400	N04400	...	Quiet immersion in storage tank	25	35 (95)	112 d	0.04 (1.6)	...	79
Nickel 200	N02200	...	In evaporator concentrating solution	To 57	115 (240)	...	1.5 (59)	...	44
Nickel 200	N02200	...	In evaporator concentrating solution	To 57	115 (240)	44 d	1.475 (59)	...	79
Nickel 200	N02200	...	Quiet immersion in storage tank	25	35 (95)	...	0.015 (0.6)	...	44

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	Quiet immersion in storage tank	25	35 (95)	112 d	0.015 (0.6)	...	79
Refractory metals and alloys									
Hafnium	...	...	...	25	...	10 d	Resistant	...	11
Hafnium	...	...	...	25	...	10 d	Resistant	...	11
Niobium	R04210	...	...	25	Boiling	...	Resistant	...	2
Titanium	...	...	...	10	80 (176)	...	0.05 (2)	...	90
Titanium	...	...	...	10	Boiling	...	0.12 (4.8)	...	90
Titanium	...	...	Plus 1% H_2SO_4	Saturated	Room	...	Resistant	...	90
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Zr702	R60702	...	...	25	Boiling	...	Resistant	...	62
Zr702	R60702	...	...	25	Boiling	...	Resistant	...	15
Zr702	R60702	...	...	60	100 (212)	...	0.05 (2) max	...	15
Zr705	R60705	...	...	25	Boiling	...	Resistant	...	62
Zr705	R60705	...	...	25	Boiling	...	Resistant	...	15
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Good	...	253
301	S30100	...	...	Saturated	20 (68)	...	Good	...	253
301	S30100	...	...	Saturated	Boiling	...	Questionable	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Good	...	253
302	S30200	...	...	Saturated	20 (68)	...	Good	...	253
302	S30200	...	...	Saturated	Boiling	...	Questionable	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	Saturated	20 (68)	...	Questionable	...	253
303	S30300	...	...	Saturated	20 (68)	...	Good	...	253
303	S30300	...	...	Saturated	Boiling	...	Poor	...	253
303	S30300	...	...	Saturated	Boiling	...	Questionable	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Good	...	253
304	S30400	...	...	Saturated	20 (68)	...	Good	...	253
304	S30400	...	...	Saturated	Boiling	...	Questionable	...	253
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation	20-60	118 (244)	36 d	0.75 (30)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. pH 2-3	50-55	107-113 (225-235)	8 d	15 (630)	Severe pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; no agitation	20-60	118 (244)	36 d	0.23 (9)	...	89
304	S30400	...	Research lab test. With carbon over the standard minimum	30-40	79 (175)	6 d	Resistant	...	89
304	S30400	...	Research lab test; no aeration; slight to moderate agitation	40-50	88 (190)	6 d	1.5 (60)	...	89
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	Saturated	20 (68)	...	Good	...	253
304L	S30403	...	...	Saturated	Boiling	...	Questionable	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Good	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Good	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Questionable	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Good	...	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. pH 2-3	50-55	107-113 (225-235)	8 d	5 (200)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation	20-60	118 (244)	36 d	0.23 (9)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; no agitation	20-60	118 (244)	36 d	0.1 (4)	...	89
316	S31600	...	Research lab test	30-40	79 (175)	6 d	0.0005 (0.2)	...	89
316	S31600	...	Research lab test; no aeration; slight to moderate agitation	40-50	88 (190)	6 d	0.008 (0.3)	...	89
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Good	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Good	...	253
316F	S31620	...	...	Saturated	Boiling	...	Questionable	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Good	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Good	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Good	...	253
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. pH 2-3	50-55	107-113 (225-235)	8 d	2.3 (90)	...	89
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Good	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Good	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Good	...	253
321	S32100	...	...	Saturated	20 (68)	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	Saturated	Boiling	...	Questionable	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Good	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Good	...	253
347	S34700	...	...	Saturated	20 (68)	...	Good	...	253
347	S34700	...	...	Saturated	Boiling	...	Questionable	...	253
403	S40300	...	...	10	20 (68)	...	Questionable	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	...	Saturated	20 (68)	...	Questionable	...	253
403	S40300	...	...	Saturated	Boiling	...	Poor	...	253
405	S40500	...	...	10	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Questionable	...	253
405	S40500	...	...	Saturated	Boiling	...	Poor	...	253
409	S40900	...	...	10	20 (68)	...	Questionable	...	253
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Questionable	...	253
409	S40900	...	...	Saturated	Boiling	...	Poor	...	253
410	S41000	...	...	10	21 (70)	...	Poor	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	10	20 (68)	...	Questionable	...	253
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	...	Saturated	20 (68)	...	Questionable	...	253
410	S41000	...	...	Saturated	Boiling	...	Poor	...	253
410	S41000	...	Plus 1.0% H_2SO_4	Saturated	Room	...	Poor	...	121
410	S41000	...	Plus 1.0% soluble carbonate	Saturated	Room	...	Resistant	...	121
416	S41600	...	...	10	20 (68)	...	Questionable	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	...	Saturated	20 (68)	...	Questionable	...	253
416	S41600	...	...	Saturated	Boiling	...	Poor	...	253
420	S42000	...	...	10	20 (68)	...	Questionable	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Questionable	...	253
420	S42000	...	...	Saturated	Boiling	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Poor	...	121
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	Saturated	20 (68)	...	Questionable	...	253
430	S43000	...	...	Saturated	Boiling	...	Poor	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	Saturated	20 (68)	...	Questionable	...	253
434	S43400	...	...	Saturated	Boiling	...	Poor	...	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
Carpenter 20	...	...	Research lab test	30-40	79 (175)	6 d	0.0015 (0.6)	...	89
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Good	...	253

Amino Acetic Acid and Acetamide

Amine salts have achieved special importance as corrosion inhibitors for protecting inexpensive materials such as aluminum alloys and low-alloy steels against corrosion in salt and acid solutions. Generally speaking, a good effect is already achieved with additions of 0.0001 to 0.01 mol L^{-1}.

Paper impregnated with certain amine salts is used to wrap components of copper or silver alloys to protect them against corrosion during long storage periods in industrial atmospheres. Typical salts used are hexamethyleneimine-o-nitrobenzoate and piperidine-3.5-dinitrobenzoate because they readily evaporate.

The use of coatings of polyethylene and epoxy copolymers or fluorocarbon resins is essential for protection against some corrosive amine salts such as, 4-diazo-3-nitroanisole sulfate and hydroxylamine sulfate solutions at elevated temperatures, at which even high-grade chromium-nickel-molybdenum steels corrode severely. Amine salts at high concentrations can cause severe corrosion of some metals and alloys.

Corrosion Behavior of Various Metals and Alloys in Amino Acetic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Al-1Mn-2Mg	...	...	10% H_2O	...	22 (72)	360 d	.0066 (0.26)	...	258
Al-1Mn-2Mg	...	...	50% H_2O	...	22 (72)	360 d	.0086 (0.34)	...	258
Al-3Mg	...	...	50% H_2O	...	22 (72)	360 d	.0200 (0.78)	...	258

Corrosion Behavior of Various Metals and Alloys in Acetamide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Al-1Mn-2Mg	...	...	10% H_2O	...	22 (72)	360 d	.0032 (0.12)	...	258
Al-1Mn-2Mg	...	...	50% H_2O	...	22 (72)	360 d	...	...	258
Al-3Mg	...	...	10% H_2O	...	22 (72)	360 d	.0033 (0.13)	...	258
Al-3Mg	...	...	50% H_2O	...	22 (72)	360 d	.0040 (0.16)	...	258

Ammonia

Ammonia, NH_3, is a colorless gaseous alkaline compound with a melting point of –77.7 °C and a boiling point of –33.35 °C. It is very soluble in water, has a highly characteristic pungent odor, is lighter than air, and is formed as a result of the decomposition of most nitrogenous organic materials. Anhydrous ammonia, a major commercial chemical, is used in the manufacture of fertilizers, HNO_3, acrylonitrile, and other products, and as an electrolytic solvent.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon Steels. Except for a sensitivity to stress-corrosion cracking, carbon steel is fully acceptable in ammonia service. In most cases, the developing cracks have been detected by inspection before leakage or rupture. However, there have been a few catastrophic failures. For example, in France in 1968, a tanker ruptured, killing 5 people. A second case was in South Africa, where a large tank failed in 1973 with 22 fatalities. The primary causes of the cracking are high stresses and air contamination. Nitrogen and carbon dioxide were suggested by separate investigators as promoting stress-corrosion cracking. Cracking is accelerated by the use of high-strength steels, the presence of hard welds, and

air contamination. The cracking mechanism can be inhibited by water above about 0.1%. Thermal stress relief, if done properly, reduces stress below the critical level.

Alloy Steels. Low-alloy steel storage tanks have been used for many years for storage of ammonia. Stress-corrosion cracking has been the primary corrosion problem in vessels used for ammonia storage. It has been shown in several investigations that high stresses and oxygen (air) contamination are the primary causes of such cracking and that the addition of 0.1 to 0.2% water inhibits stress-corrosion cracking in alloy steel storage vessels.

Stainless Steels. In ammonia and ammonium hydroxide (NH_4OH), stainless steels have shown good resistance at all concentrations up to the boiling point.

Aluminum. In laboratory tests, 1100, 3003 and other copper-free aluminum alloys have been found to be resistant to dry, gaseous ammonia even at elevated temperatures. Alloys 1100 and 3003 were also resistant to pure anhydrous liquid ammonia, but contaminants can result in pitting of the metal. In dilute ammonia solutions (up to ~10%), the initial rate of attack is controlled by diffusion of OH ions to the aluminum surface and is a function of pH. Passivation of the aluminum surface occurs when a critical amount of corrosion product builds up at the aluminum surface, forming a protective film. If solution saturation of soluble corrosion product is relieved before passivation, film formation may not occur. A careful analysis of exposure conditions is required in using aluminum alloys in dilute ammonia. Aluminum alloys have been used in refrigeration systems handling liquid ammonia containing up to 5% water and in producing synthetic ammonia. Aluminum alloy compressors, heat exchangers, evaporators, condensers, and piping have been used in producing ammonia. Aluminum alloy pressure vessels have been used for storing and transporting ammonia. Carbon dioxide and hydrogen sulfide have been used to inhibit corrosion under condensing conditions.

Copper. Ammonia and ammonium compounds are the corrosive substances most often associated with stress-corrosion cracking of copper alloys. All copper-base alloys can be made to crack in ammonia vapor, ammonia solutions, ammonium ion solutions, and environments in which ammonia is a reaction product. These compounds are sometimes present in the atmosphere; in other cases, they are in cleaning compounds or in chemicals used to treat boiler water.

Both oxygen and moisture must be present for ammonia to be corrosive to copper alloys; other compounds, such as CO_2, are thought to accelerate stress-corrosion cracking in ammonia atmospheres. Moisture films on metal surfaces will dissolve significant quantities of ammonia, even from atmospheres with low ammonia concentrations. The rate at which cracks develop is critically dependent on many variables, including stress level, specific alloy, oxygen concentration in the liquid, pH or ammonia concentration, copper ions concentration, and potential.

Stress-corrosion cracking occurs in a great variety of brasses that differ widely in composition, degree of purity, and microstructure. The behavior of a copper alloy subjected to the combined effect of tensile stress and ammonia is an index of susceptibility to stress-corrosion cracking. Susceptibility to stress-corrosion cracking diminishes as the copper content of the brass is increased.

Protracted heating of 70Cu-30Zn brass at 100 °C (212 °F) does not develop cracks and does not reduce the internal stress appreciably. Surface defects that localize stresses do not appear to contribute to the development of cracks in the absence of an essential corroding agent, such as ammonia.

Severe corrosion and pitting do not of themselves lead to cracking. Cracks often follow an intercrystalline path.

Traces of ammonia in the environment are an important agent in inducting stress-corrosion cracking in atmospheric exposure. Ammonia has a specific and selective action on the material in the grain boundaries of brass. Cracking always begins in surface layers that are under tension.

Copper and its alloys are suitable for handling anhydrous ammonia if the ammonia remains anhydrous and if not contaminated with water and oxygen. In one test conducted for 1200 h, C11200 and C26000 each showed an average penetration of 5 μm/yr (0.2 mil/yr) in contact with anhydrous ammonia at atmospheric temperature and pressure. Tests showed the rates of corrosion to be low in the presence of small amounts of water, but oxygen was probably excluded. Aluminum bronzes should be avoided for service in moist ammonia.

Magnesium. Ammonia, wet or dry, causes no attack on magnesium at ordinary temperatures. Some corrosion may occur if water vapor is present.

Tin. Tin is not reactive with dry ammonia, and saturated ammonia solutions do not attack tin. More dilute solutions, however, behave like other alkaline solutions of comparable pH.

Titanium. The oxide film on titanium alloys provides an effective barrier to attack by most gases in wet or dry conditions, including ammonia. This protection extends to temperatures in excess of 150 °C (300 °F).

Zirconium. Zirconium is stable in ammonia at temperatures up to about 1000 °C (1830 °F).

Corrosion Behavior of Various Metals and Alloys in Ammonia

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Moist gas	...	...	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Solution	...	...	...	Resistant	...	92
Aluminum-magnesium alloys	...	...	Moist gas	...	...	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonia (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
Ampco 8, aluminum bronze	C61300	...	Dry. Generally suitable. Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Ampco 8, aluminum bronze	C61300	...	Wet. Generally not suitable	...	...	...	0.5 (20) min	...	96
C11000	C11000	...	Liquid plus 1% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72
C11000	C11000	...	Liquid plus 2% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1)	...	72
C11000	C11000	...	Liquid. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test,depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1)	...	72
C11000	C11000	...	Vapor plus 1% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72
C11000	C11000	...	Vapor plus 2% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1)	...	72
C11000	C11000	...	Vapor. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test,depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonia (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
C26000	C26000	...	Liquid plus 1% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1)	...	72
C26000	C26000	...	Liquid with 2% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.005 (0.2)	...	72
C26000	C26000	...	Liquid. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72
C26000	C26000	...	Vapor plus 1% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72
C26000	C26000	...	Vapor with 2% water. Any air present was probably depleted during initial stages of test. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1)	...	72
C26000	C26000	...	Vapor. Atmospheric temperature and pressure of 345 to 1035 kPa (50 to 150 psi). Specimens were placed at the top and bottom of 2-L bombs that were charged with ammonia. Pressure varied throughout the test, depending on temperature. Water was added to two of the bombs before charging with ammonia	...	...	1600 h	0.003 (0.1) max	...	72
Nickel- silver	...	...	Absolutely dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Poor	...	93
Phosphor copper	C12200	...	Absolutely dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Poor	...	93
Red brass	C23000	...	Absolutely dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	Absolutely dry	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonia (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silicon bronze, high	C65500	...	Moist	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	Absolutely dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	10-30	24-100 (75-212)	...	0.5 (20) max	...	95
Magnesium	...	...	Gas or liquid	100	Room	...	Resistant	...	119
Platinum	P04995	...	With oxidant. Use of Pt-Rh alloys is preferred for ammonia oxidation (loss is <250 mg of Pt/ton of HNO_3)	...	950 (1740)	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	190 (375)	...	0.05 (2) max	...	8
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing (urea manufacture); field or pilot plant test; no aeration; rapid agitation. Plus 7% carbon dioxide, remainder water (half immersed)	12	29 (85)	16 d	0.038 (15)	...	89
Alloy 825	N08825	...	Metal (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14% carbon dioxide, remainder water (still overhead line)	26	82 (180)	65 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; no aeration; slight to moderate agitation. Plus 71% water,7% carbon dioxide, trace ammonium nitrate, pressure 29 psig (ammonia surge vessel, bottom)	22	65 (150)	300 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus water, low carbon dioxide (ammonia desorber, vapors below liquid trapout tray)	20	102 (215)	250 d	0.005 (0.2)	...	89
Alloy 825	N08825	...	Plastic processing; field or pilot plant test; no aeration; no agitation. Plus hydrogen cyanide, carbon dioxide, and water	90	105 (221)	30 d	0.003 (0.1)	...	89
Refractory metals and alloys									
Titanium	...	...	Anhydrous	100	40 (104)	...	0.127 (5.08) max	...	90
Titanium	...	...	Plus steam + water	...	222 (432)	...	11.2 (448)	...	90
Zr702	R60702	...	Wet. Plus H_2O	...	38 (100)	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	21 (70)	...	Resistant	...	121
304	S30400	...	...	...	...	...	Resistant	...	253
304	S30400	...	Chemical processing (urea manufacture); field or pilot plant test; no aeration; rapid agitation. Plus 7% carbon dioxide, remainder water (half immersed)	12	29 (85)	16 d	2.0 (78)	...	89
304	S30400	...	Metal (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14% carbon dioxide, remainder water (still overhead line)	26	82 (180)	65 d	0.003 (0.1) max	...	89

(Continued)

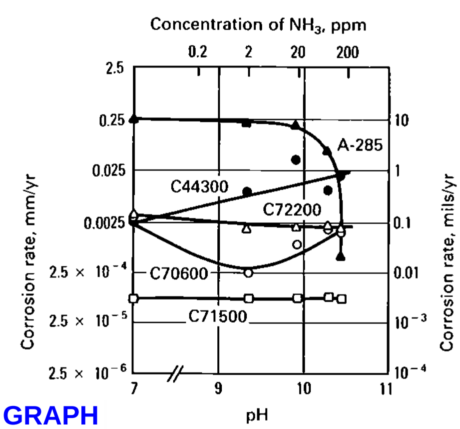
Corrosion Behavior of Various Metals and Alloys in Ammonia (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Metal processing; field or pilot plant test; no aeration; rapid agitation. Plus nickel, cobalt, copper and ammonium sulfates, water solution, solids as 2% copper sulfide, 4-5% vapors of ammonia and water vapor (copper boil reboiler)	8.4	101-107 (215-225)	95 d	0.003 (0.1) max	...	89
304	S30400	...	Metal processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14% oxygen, saturated with water vapor, remainder nitrogen (leach autoclave, vapors)	9	76-82 (170-180)	111 d	0.003 (0.1) max	...	89
304	S30400	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; no aeration; slight to moderate agitation. Plus 71% water, 7% carbon dioxide, trace ammonium nitrate, pressure 29 psig (ammonia surge vessel, bottom)	22	65 (150)	300 d	0.008 (0.3)	...	89
304	S30400	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus water, low carbon dioxide (ammonia desorber, vapors below liquid trapout tray)	20	102 (215)	250 d	0.083 (3.3)	...	89
304	S30400	...	Plastic processing; field or pilot plant test; no aeration; no agitation. Plus hydrogen cyanide, carbon dioxide, and water	90	105 (221)	30 d	0.003 (0.1)	Severe pitting	89
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	21 (70)	...	Resistant	...	121
316	S31600	...	...	...	...	...	Resistant	...	253
316	S31600	...	Chemical processing (urea manufacture); field or pilot plant test; no aeration; rapid agitation. Plus 7% carbon dioxide, remainder water (half immersed)	12	29 (85)	16 d	360 (19)	...	89
316	S31600	...	Metal (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14% carbon dioxide, remainder water (still overhead line)	26	82 (180)	65 d	0.003 (0.1) max	...	89
316	S31600	...	Metal processing; field or pilot plant test; no aeration; rapid agitation. Plus nickel, cobalt, copper and ammonium sulfates, water solution, solids as 2% copper sulfide, 4-5% vapors of ammonia and water vapor (copper boil reboiler)	8.4	101-107 (215-225)	95 d	0.003 (0.1) max	...	89
316	S31600	...	Metal processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 14% oxygen, saturated with water vapor, remainder nitrogen (leach autoclave, vapors)	9	76-82 (170-180)	111 d	0.003 (0.1) max	...	89
316	S31600	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus water, low carbon dioxide (ammonia desorber, vapors below liquid trapout tray)	20	102 (215)	250 d	0.015 (0.6)	...	89
316	S31600	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; no aeration; slight to moderate agitation. Plus 71% water, 7% carbon dioxide, trace ammonium nitrate, pressure 29 psig (ammonia surge vessel, bottom)	22	65 (150)	300 d	0.003 (0.1) max	...	89

(Continued)

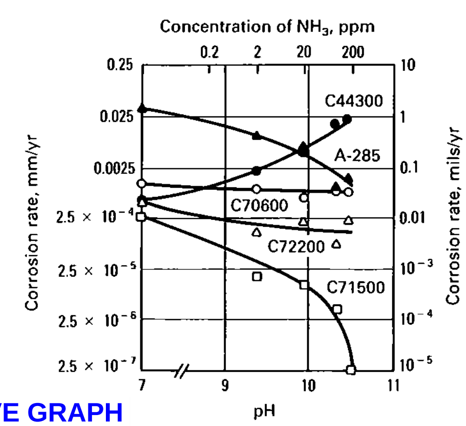
Corrosion Behavior of Various Metals and Alloys in Ammonia (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Plastic processing; field or pilot plant test; no aeration; no agitation. Plus hydrogen cyanide, carbon dioxide, and water	90	105 (221)	30 d	0.003 (0.1)	...	89
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Resistant	...	253
405	S40500	...	...	...	...	...	Resistant	...	253
409	S40900	...	...	...	...	...	Resistant	...	253
410	S41000	...	...	...	21 (70)	...	Resistant	...	121
410	S41000	...	...	...	...	...	Resistant	...	253
416	S41600	...	...	...	...	...	Resistant	...	253
420	S42000	...	...	...	...	...	Resistant	...	253
430	S43000	...	...	...	21 (70)	...	Resistant	...	121
430	S43000	...	...	...	...	...	Resistant	...	253
434	S43400	...	...	...	...	...	Resistant	...	253
Carpenter 20	...	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus water, low carbon dioxide (ammonia desorber, vapors below liquid trapout tray)	20	102 (215)	250 d	0.005 (0.2)	...	89
Carpenter 20	...	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; no aeration; slight to moderate agitation. Plus 71% water, 7% carbon dioxide, trace ammonium nitrate, pressure 29 psig (ammonia surge vessel, bottom)	22	65 (150)	300 d	0.01 (0.4)	...	89
Carpenter 20	...	...	Plastic processing; field or pilot plant test; no aeration; no agitation. Plus hydrogen cyanide, carbon dioxide, and water	90	105 (221)	30 d	0.003 (0.1)	...	89
F51	S31803	...	...	...	...	...	Resistant	...	253



LIVE GRAPH
Click here to view

Copper alloys. Corrosion rates of copper alloys in aerated NH_3 solutions. Test duration: 1000 h. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 622.



LIVE GRAPH
Click here to view

Copper alloys. Corrosion rates of copper alloys in deaerated NH_3 solutions. Test duration: 1000 h. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 622.

Ammonium Aluminum Sulfate

Ammonium aluminum sulfate, $NH_4Al(SO_4)_2 \cdot 12H_2O$, is colorless, odorless water-soluble crystals, which melt at 94 °C. Also known as ammonium alum, aluminum ammonium sulfate, it is used in manufacturing medicines and baking powder, and in dyeing, tanning, and papermaking.

Corrosion Behavior of Various Metals and Alloys in Ammonium Aluminum Sulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Poor	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Poor	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Poor	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Poor	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Poor	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Poor	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Questionable	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Poor	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Questionable	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Questionable	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Questionable	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Questionable	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Poor	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Questionable	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Poor	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Questionable	...	253

Ammonium Bicarbonate

Ammonium bicarbonate, NH_4HCO_3, also referred to as ammonium hydrogen carbonate and ammonium acid carbonate, is a white solid, soluble in water, that forms by the reaction of ammonium hydroxide and excess CO_2.

Corrosion Behavior of Various Metals and Alloys in Ammonium Bicarbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Ammonium Bifluoride

Ammonium bifluoride, NH_4HF_2, is a white water soluble substance, also referred to as ammonium hydrogen fluoride, ammonium difluoride and ammonium acid fluoride.

Corrosion Behavior of Various Metals and Alloys in Ammonium Bifluoride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickels and alloys									
Alloy 600	N06600	...	...	15	25 (77)	...	.025 (1.0)	...	257
Alloy 600	N06600	...	...	75	200 (390)	...	.22 (8.7)	...	257
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Poor	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Poor	...	253
410	S41000	...	...	Saturated	20 (68)	...	Poor	...	253
416	S41600	...	...	Saturated	20 (68)	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Poor	...	253
430	S43000	...	...	Saturated	20 (68)	...	Poor	...	253
434	S43400	...	...	Saturated	20 (68)	...	Questionable	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253

Ammonium Bisulfate

This compound is one of several salts that can form from the reaction of ammonia and sulfur bearing gases, most particularly sulfur trioxide. This product is frequently found in the overhead of crude distillation units and can be quite corrosive to steel equipment. Chemical corrosion inhibitors are often used to control corrosion from ammonium bisulfate.

Corrosion Behavior of Various Metals and Alloys in Ammonium Bisulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	Saturated solution	...	138 (280)	14 d	6.4 (250)	...	228
Carbon steel	G10100	...	Saturated solution	...	149 (300)	14 d	6.4 (250)	...	228
Copper and alloys									
Admiralty brass	C44300	...	Saturated solution	...	138 (280)	14 d	.051 (2)	...	228
Admiralty brass	C44300	...	Saturated solution	...	149 (300)	14 d	.15 (6)	...	228

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Bisulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Alloy 400	N04400	...	Saturated solution	...	138 (280)	14 d	.05 (2)	...	228
Alloy 400	N04400	...	Saturated solution	...	149 (300)	14 d	.36 (14)	...	228
Refractory metals and alloys									
Titanium, grade 12	R53400	...	Saturated solution	...	138 (280)	14 d	.051 (2)	...	228
Titanium, grade 12	R53400	...	Saturated solution	...	149 (300)	14 d	.13 (5)	...	228

Ammonium Carbonate

Ammonium carbonate, $(NH_4)_2CO_3$, is a white water-soluble, volatile solid prepared by reaction of NH_4OH and CO_2 and crystallizing from dilute alcohol. Ammonium carbonate loses NH_3, CO_2, and H_2O at ordinary temperatures, and rapidly at 58 °C.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests under conditions of 100% relative humidity and ambient temperature, aluminum alloy 3003 showed resistance, whereas aluminum alloy 5154 was mildly attacked by solid ammonium carbonate. Aluminum alloy 3003 showed resistance in other tests to aqueous solutions of 1, 5, and 50% ammonium carbonate. Piping and storage tanks of aluminum alloys have been used to handle ammonium carbonate.

Iridium. Iridium is resistant to anodic corrosion in aqueous electrolytes, but may be attacked in ammonium carbonate solutions under the action of an alternating current.

Corrosion Behavior of Various Metals and Alloys in Ammonium Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20-70 (68-158)	...	Resistant	...	92
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. With carbon over the standard maximum. Plus ammonia, pH 9-10	...	29-46 (85-115)	41 d	0.003 (0.1)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Carbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus ammonia, pH 9-10	...	29-46 (85-115)	41 d	0.003 (0.1)	...	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Resistant	...	253
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Resistant	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	...	1	21 (70)	...	Good	...	121
410	S41000	...	...	5	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Resistant	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Resistant	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253
420	S42000	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	...	1	21 (70)	...	Good	...	121
430	S43000	...	...	5	21 (70)	...	Good	...	121
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Ammonium Chloride

Ammonium chloride, NH_4Cl, also known as ammoniae, salmiai, and ammonium nituriate, is a white crystalline solid. It is soluble in water, aqueous solutions of ammonia, and is slightly soluble in methyl alcohol. Ammonium chloride is found in nature as a sublimation product of volcanic activity, or is produced by neutralizing HCl (either in liquid or gaseous phase) with NH_3 gas or liquid NH_4OH then evaporating the excess H_2O. The salt decomposes at 350 °C and sublimes under controlled conditions at 520 °C. Ammonium chloride is used as an electrolyte in dry cell batteries, as a flux for soldering, tinning and galvanizing, and as a processing ingredient in textile printing and hide tanning. Use as a source of nitrogen for fertilizers is limited because of the possible build-up of damaging chloride residuals in the soil.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests at 100% relative humidity and ambient temperature, aluminum alloy 3003 suffered moderate attack (~6 mils/yr) by solid ammonium chloride. Aqueous solutions (up to 20%) of ammonium chloride caused mild attack (~3 mils/yr) but localized pitting at all concentrations on aluminum alloy 1100 at ambient temperature. At the boiling point, concentrated solutions of ammonium chloride are very corrosive.

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20-70 (68-1158)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20-70 (68-158)	...	Resistant	...	92
Carbon and alloy steels									
Carbon steel	G10100	...	Saturated solution	...	138 (280)	14 d	1.5 (60)	...	228
Carbon steel	G10100	...	Saturated solution	...	149 (300)	14 d	3.3 (130)	...	228
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	Saturated solution	...	138 (280)	14 d	0.18 (0.7)	...	228
Admiralty brass	C44300	...	Saturated solution	...	149 (300)	14 d	0.18 (0.7)	...	228
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	0-10	24 (75)	...	0.5 (20) max	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Silver	P07010	...	Vapor	...	200 (390)	...	Poor	...	8
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Alloy 400	N04400	...	Saturated solution	...	138 (280)	14 d	.025 (1)	...	228
Alloy 400	N04400	...	Saturated solution	...	149 (300)	14 d	.051 (2)	...	228
Alloy 625	N06625	...	...	Saturated	204 (400)	10 d	0.10 (3.8)	...	216
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5 (transfer line)	75	49 (120)	12 d	0.003 (0.1)	...	89
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.003 (0.1) max	Moderate pitting. Crevice attack	89
Alloy C-276	N10276	...	...	Saturated	204 (400)	10 d	0.04 (1.4)	...	216
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	42 d	0.003 (0.1) max	Pitting after 42 d	44
Inconel 718	N07718	...	...	Saturated	204 (400)	10 d	0.14 (5.7)	...	216
Inconel 601	N06601	...	...	5	80 (176)	30 d	0.002 (0.1)	Pitting attack	64
Monel 400	N04400	...	In evaporator concentrating solution	28-40	102 (216)	32 d	0.3 (12.0)	...	79
Nickel 200	N02200	...	In evaporator concentrating solution	28-40	102 (216)	...	0.21 (8.4)	...	44
Nickel 200	N02200	...	In evaporator concentrating solution	28-40	102 (216)	32 d	0.21 (8.4)	...	79
Refractory metals and alloys									
Stellite 6	...	Weld overlay	...	Saturated	204 (400)	10 d	0.04 (1.6)	...	216
Tantalum	R05210	...	...	10	100 (212)	...	Resistant	...	42
Titanium, grade 12	R53400	...	Tight crevices pH 4.1	10	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 4.1	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 4.1	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 4.1	10	Boling	...	Poor	...	215
Titanium, grade 7	R52400	...	Tight crevices pH 4.1	10	Boiling	...	Resistant	...	215
Titanium	...	...	...	Saturated	100 (212)	...	0.013 (0.52) max	...	90
Titanium, grade 12	R53400	...	...	10	Boiling	...	Resistant	...	33
Titanium, grade 12	R53400	...	Saturated solution	...	138 (280)	14 d	.003 (0.1) max	...	228
Titanium, grade 12	R53400	...	Saturated solution	...	149 (300)	14 d	.003 (0.1)	...	228
Zr702	R60702	...	...	1	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	10	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	Saturated	35-100 (95-212)	...	0.025 (1) max	...	15
Stainless steels									
20Cb-3	N08020	...	...	Saturated	204 (400)	10 d	0.05 (2.0)	Pitting 70 mils	216
301	S30100	...	...	10	Boiling	...	Resistant	Pitting	253
301	S30100	...	...	25	Boiling	...	Good	Pitting	253
301	S30100	...	...	50	Boiling	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	Saturated	Boiling	...	Good	Pitting	253
302	S30200	...	...	10	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	25	Boiling	...	Good	Pitting	253
302	S30200	...	...	50	Boiling	...	Good	Pitting	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	Saturated	Boiling	...	Good	Pitting	253
303	S30300	...	...	10	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	10	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	25	Boiling	...	Good	Pitting	253
303	S30300	...	...	25	Boiling	...	Good	Pitting	253
303	S30300	...	...	50	Boiling	...	Good	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated	Boiling	...	Good	Pitting	253
303	S30300	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
304	S30400	...	...	10	Boiling	...	Poor	Susceptible to pitting and stress-corrosion cracking	121
304	S30400	...	...	10	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	25	Boiling	...	Good	Pitting	253
304	S30400	...	...	50	Boiling	...	Good	Pitting	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	Saturated	Boiling	...	Good	Pitting	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.015 (0.6)	Severe pitting	89
304	S30400	Sensitized	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.02 (0.8)	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.008 (0.3)	...	89
304	S30400	Sensitized	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.018 (0.7)	...	89
304	S30400	...	Chemical processing; field or pilot test; no aeration; slight to moderate agitation. Plus water (tubular gas cooler), 2% ammonia, 3% carbon dioxide, 8% sodium chloride	18	30-80 (86-176)	68 d	0.003 (0.1) max	...	89
304	S30400	...	Lab test; no aeration; no agitation. Plus 33% zinc chloride, 34% water	33	60 (140)	33 d	0.033 (1.3)	Severe pitting	89
304L	S30403	...	...	10	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	25	Boiling	...	Good	Pitting	253
304L	S30403	...	...	50	Boiling	...	Good	Pitting	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	Saturated	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	10	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	25	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	50	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	Saturated	Boiling	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	10	Boiling	...	Good	...	121
316	S31600	...	...	10	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	25	Boiling	...	Good	Pitting	253
316	S31600	...	...	50	Boiling	...	Good	Pitting	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	Saturated	Boiling	...	Good	Pitting	253
316	S31600	Annealed	All solutions from CP chemicals. Tests made in the lab	10	Boiling	...	0.025 (1) max	...	19
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.003 (0.1) max	Moderate pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.005 (0.2)	...	89
316	S31600	Sensitized	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.01 (0.4)	...	89
316	S31600	Sensitized	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.013 (0.5)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot test; no aeration; slight to moderate agitation. Plus water (tubular gas cooler), 2% ammonia, 3% carbon dioxide, 8% sodium chloride	18	30-80 (86-176)	68 d	0.003 (0.1) max	...	89
316	S31600	...	Lab test; no aeration; no agitation. Plus 33% zinc chloride, 34% water	33	60 (140)	33 d	0.003 (0.1)	Severe pitting	89
316	S31600	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
316F	S31620	...	...	10	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	25	Boiling	...	Good	Pitting	253
316F	S31620	...	...	50	Boiling	...	Good	Pitting	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	Saturated	Boiling	...	Good	Pitting	253
316L	S31603	...	...	10	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	25	Boiling	...	Good	Pitting	253
316L	S31603	...	...	50	Boiling	...	Good	Pitting	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated	Boiling	...	Good	Pitting	253
316L	S31603	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
316LN	S31653	...	...	10	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	25	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	50	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated	Boiling	...	Good	Pitting	253
316LN	S31653	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	25	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	50	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated	Boiling	...	Good	Pitting	253
316Ti	S31635	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.008 (0.3)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.003 (0.1) max	Severe pitting	89
317L	S31703	...	...	10	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	25	Boiling	...	Good	Pitting	253
317L	S31703	...	...	50	Boiling	...	Good	Pitting	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated	Boiling	...	Good	Pitting	253
317L	S31703	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
317LN	S31725	...	...	10	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	25	Boiling	...	Good	Pitting	253
317LN	S31725	...	...	50	Boiling	...	Good	Pitting	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated	Boiling	...	Good	Pitting	253
317LN	S31725	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
321	S32100	...	...	10	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	25	Boiling	...	Good	Pitting	253
321	S32100	...	...	50	Boiling	...	Good	Pitting	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	Saturated	Boiling	...	Good	Pitting	253
329	S32900	...	...	10	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	25	Boiling	...	Good	Pitting	253
329	S32900	...	...	50	Boiling	...	Good	Pitting	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated	Boiling	...	Good	Pitting	253
329	S32900	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
347	S34700	...	...	10	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	25	Boiling	...	Good	Pitting	253
347	S34700	...	...	50	Boiling	...	Good	Pitting	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	Saturated	Boiling	...	Good	Pitting	253
403	S40300	...	...	10	Boiling	...	Good	Pitting	253
403	S40300	...	...	25	Boiling	...	Good	Pitting	253
403	S40300	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	10	Boiling	...	Good	Pitting	253
405	S40500	...	...	25	Boiling	...	Good	Pitting	253
405	S40500	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	10	Boiling	...	Good	Pitting	253
409	S40900	...	...	25	Boiling	...	Good	Pitting	253
409	S40900	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	10	Boiling	...	Poor	...	121
410	S41000	...	...	10	Boiling	...	Good	Pitting	253
410	S41000	...	...	25	Boiling	...	Good	Pitting	253
410	S41000	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
416	S41600	...	...	10	Boiling	...	Good	Pitting	253
416	S41600	...	...	25	Boiling	...	Good	Pitting	253
416	S41600	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	10	Boiling	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	25	Boiling	...	Good	Pitting	253
420	S42000	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	10	Boiling	...	Poor	...	121
430	S43000	...	...	10	Boiling	...	Resistant	Pitting	253
430	S43000	...	...	25	Boiling	...	Good	Pitting	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
430	S43000	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	10	Boiling	...	Resistant	Pitting	253
434	S43400	...	...	25	Boiling	...	Questionable	Pitting	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
434	S43400	...	Plus copper and zinc chlorides	...	Boiling	...	Poor	Pitting	253
AL 2205	S31803	...	In sealed tube under nitrogen	Saturated	204 (400)	10 d	0.12 (4.8)	...	216
AM-363	S36300	...	...	...	Room	...	Poor	...	120
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	12 d	0.005 (0.2)	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol, water, sodium chloride, pH 6.5-8.5	75	49 (120)	183 d	0.003 (0.1) max	Moderate pitting. Crevice attack	89
F51	S31803	...	...	10	Boiling	...	Resistant	Pitting	253
F51	S31803	...	...	25	Boiling	...	Good	Pitting	253
F51	S31803	...	...	50	Boiling	...	Good	Pitting	253

Ammonium Fluoride

Ammonium fluoride, NH_4F, is a white crystalline salt that is soluble in cold water. It is unstable and emits a strong odor of ammonia. Ammonium fluoride is used in etching glass, preserving wood, and in the textile industry as a mordant.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Solid ammonium fluoride caused mild attack (~3 mils/yr) of aluminum alloy 3003 under laboratory conditions of 100% relative humidity and ambient temperature. Other tests proved aluminum alloy 1100 resistant to solutions of 10 to 25% ammonium fluoride at ambient temperature. However, solutions of 50% concentration were very corrosive to aluminum alloy 3003 at 93 °C (200 °F).

Corrosion Behavior of Various Metals and Alloys in Ammonium Fluoride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; lab test; no aeration; rapid agitation. Ammonium hydroxide excess, pH moderately basic	15	51 (125)	94 d	0.003 (0.01) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Fluoride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	...	Field or pilot plant test; slight to moderate aeration; no agitation. Water solution	10	25 (77)	61 d	0.013 (0.5)	...	89
Alloy 825	N08825	...	Metal processing; field or pilot plant test; slight to moderate aeration; rapid agitation; 50% to anhydrous ammonium bifluoride, unidentified ore	50	27-199 (80-390)	10 d	0.18 (7.1)	...	89
Refractory metals and alloys									
Titanium	...	...	...	10	Room	...	0.102 (4.08)	...	90
Zr702	R60702	...	pH 8	20	28 (80)	...	1.3 (50) min	...	15
Zr702	R60702	...	pH 8	20	98 (210)	...	1.3 (50) min	...	15
Stainless steels									
304	S30400	...	Chemical processing; lab test; no aeration; rapid agitation. Ammonium hydroxide excess, pH moderately basic	15	51 (125)	94 d	0.003 (0.1) max	...	89
304	S30400	...	Field or pilot plant test; slight to moderate aeration; no agitation. Water solution	10	25 (77)	61 d	0.28 (11)	...	89
304	S30400	...	Glass processing; field or pilot plant test; no aeration; no agitation. With carbon over the standard maximum. Glass-etching solution, total hydrofluoric acid, 30%, 24.8% free hydrofluoric acid, 12.5% combined ammonia, 11.5% sodium fluorosilicate	34.5	16 (60)	30 d	4.1 (165)	...	89
304	S30400	...	Glass processing; field or pilot plant test; no aeration; no agitation. Glass-etching solution, total hydrofluoric acid, 30%, 24.8% free hydrofluoric acid, 12.5% combined ammonia, 11.5% sodium fluorosilicate	34.5	16 (60)	30 d	4.4 (177)	...	89
304	S30400	...	Research; lab test; no aeration; slight to moderate agitation. Water solution	6	93 (200)	6 d	3.8 (150)	...	89
316	S31600	...	Chemical processing; lab test; no aeration; rapid agitation. Ammonium hydroxide excess, pH moderately basic	15	51 (125)	94 d	0.003 (0.1) max	...	89
316	S31600	...	Field or pilot plant test; slight to moderate aeration; no agitation. Water solution	10	25 (77)	61 d	0.24 (9.5)	...	89
316	S31600	...	Glass processing; field or pilot plant test; no aeration; no agitation. With carbon over the standard maximum. Glass-etching solution, total hydrofluoric acid, 30%, 24.8% free hydrofluoric acid, 12.5% combined ammonia, 11.5% sodium fluorosilicate	34.5	16 (60)	30 d	1.0 (40)	...	89
316	S31600	...	Research; lab test; no aeration; slight to moderate agitation. Water solution	6	93 (200)	6 d	3.5 (140)	...	89
Carpenter 20	...	...	Field or pilot plant test; slight to moderate aeration; no agitation. Water solution	10	25 (77)	61 d	0.033 (1.3)	...	89
Carpenter 20	...	...	Metal processing; field or pilot plant test; slight to moderate aeration; rapid agitation; cast specimens. 50% to anhydrous ammonium bifluoride, unidentified ore	50	27-199 (80-390)	10 d	0.24 (9.6)	...	89

Ammonium Hexachlorostannate

Also known as pink salt, $(NH_4)_2SnCl_6$ is colorless, water-soluble cubic crystals and is obtained by reaction of a concentrated ammonium chloride solution with tin tetrachloride. It is used as a mordant in dyeing.

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Corrosion Behavior of Various Metals and Alloys in Ammonium Hexachlorostannate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Good	Pitting	253
301	S30100	...	...	Saturated	60 (140)	...	Poor	Pitting	253
302	S30200	...	...	Saturated	20 (68)	...	Good	Pitting	253
302	S30200	...	...	Saturated	60 (140)	...	Poor	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Good	Pitting	253
303	S30300	...	...	Saturated	60 (140)	...	Poor	Pitting	253
303	S30300	...	...	Saturated	60 (140)	...	Poor	Pitting	253
304	S30400	...	...	Saturated	20 (68)	...	Good	Pitting	253
304	S30400	...	...	Saturated	60 (140)	...	Poor	Pitting	253
304L	S30403	...	...	Saturated	20 (68)	...	Good	Pitting	253
304L	S30403	...	...	Saturated	60 (140)	...	Poor	Pitting	253
304LN	S30453	...	...	Saturated	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	Saturated	60 (140)	...	Poor	Pitting	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	Saturated	60 (140)	...	Poor	Pitting	253
316F	S31620	...	...	Saturated	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	Saturated	60 (140)	...	Poor	Pitting	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated	60 (140)	...	Poor	Pitting	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated	60 (140)	...	Poor	Pitting	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated	60 (140)	...	Poor	Pitting	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated	60 (140)	...	Poor	Pitting	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated	60 (140)	...	Poor	Pitting	253
321	S32100	...	...	Saturated	20 (68)	...	Good	Pitting	253
321	S32100	...	...	Saturated	60 (140)	...	Poor	Pitting	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated	60 (140)	...	Poor	Pitting	253
347	S34700	...	...	Saturated	20 (68)	...	Good	Pitting	253
347	S34700	...	...	Saturated	60 (140)	...	Poor	Pitting	253
403	S40300	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
403	S40300	...	...	Saturated	60 (140)	...	Poor	Pitting	253
405	S40500	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	Saturated	60 (140)	...	Poor	Pitting	253
409	S40900	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	Saturated	60 (140)	...	Poor	Pitting	253
410	S41000	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	Saturated	60 (140)	...	Poor	Pitting	253
416	S41600	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	Saturated	60 (140)	...	Poor	Pitting	253
420	S42000	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	Saturated	60 (140)	...	Poor	Pitting	253
430	S43000	...	...	Saturated	20 (68)	...	Questionable	Pitting	253
430	S43000	...	...	Saturated	60 (140)	...	Poor	Pitting	253
434	S43400	...	...	Saturated	20 (68)	...	Good	Pitting	253
434	S43400	...	...	Saturated	60 (140)	...	Poor	Pitting	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	Saturated	60 (140)	...	Poor	Pitting	253

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Ammonium Hydroxide

Ammonium hydroxide, NH_4OH, is a hydrate of ammonia and exists in crystalline form at –79 °C. Normally, it is only found in an aqueous solution also known as aqua ammonia and ammonia water. It is prepared by dissolving NH_3 in H_2O. Reagent grade ammonium hydroxide contains from 28 to 30% NH_3 at 15.6 °C. Industrial sales specify the concentration of NH_3 in solution in terms of specific gravity. Common concentrations are 20 °Be, which would be a concentration of 17.8% NH_3 (specific gravity 0.933) and 26 °Be (specific gravity 0.897), or a concentration of 29.4% NH_3.

Ammonium hydroxide is an excellent medium for the reaction of NH_3 (which becomes the NH_4 radical in solution) with other compounds for the preparation of ammonium salts and other nitrogen-containing chemicals. It is an ingredient in deodorants, etching compounds, and cleaning and bleaching materials. Ammonium hydroxide, as aqua ammonia, finds wide use as a neutralizing agent, because it is inexpensive and strongly alkaline.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys suffer an initial rapid attack by dilute ammonium hydroxide solutions. The attack rate drops as the concentration of ammonium hydroxide and pH increase. In laboratory tests, the rate of attack of dilute ammonium hydroxide on aluminum alloy 1100 dropped from (~6 mils/yr) to less than 1 mils/yr as the concentration reached 10*N*. The rate was mild (~2 mils/yr) as the solution reached a pH value of 13. The decrease in attack has been attributed to the formation of a film on the aluminum alloy as the solution becomes oversaturated with aluminum precipitate. Processing equipment such as pressure vessels, pipes, storage tanks, and tank cars have used aluminum alloys. Aluminum bronzes are generally suitable for service in anhydrous ammonium hydroxide.

Stainless Steels. In NH_4OH, stainless steels have shown good resistance at all concentrations up to the boiling point of ammonium hydroxide.

Copper. Copper and copper alloys suffer rapid attack by concentrated solutions of ammonium hydroxide to form a soluble complex copper-ammonium compound. In some cases, the corrosion of copper exposed to dilute solutions of ammonium hydroxide is low. Copper specimens submerged at room temperature for 1 week in 0.01*N* ammonium hydroxide solution suffered a weight loss of 3.5 mil/yr.

Copper-zinc alloys are also attacked by ammonium hydroxide solutions. In laboratory tests of 2*N* ammonium hydroxide solutions at room temperature, copper-zinc alloys corrode at 1.8 to 6.6 mm/yr (70 to 260 mils/yr). Alloys containing more than 15% zinc could suffer stress-corrosion cracking, either from unrelieved residual stresses or applied service loads. Copper-nickel alloys corrode at 0.25 to 0.50 mm/yr (10 to 20 mils/yr) in 2*N* ammonium hydroxide solutions at room temperature. The corrosion rate for copper-tin alloys in 2*N* ammonium hydroxide solution is 1.3 to 2.5 mm/yr (50 to 100 mils/yr). Copper-silicon alloys corrode at a rate of 0.75 to 5 mm/yr (30 to 200 mils/yr) in a room-temperature 2*N* ammonium hydroxide solution.

Nickel. Nickel 200 resists attack by 1% concentrations of ammonium hydroxide, but stronger concentrations can cause rapid attack.

Titanium. Titanium alloys resist corrosion of boiling ammonium hydroxide solutions up to saturation. Titanium alloys may eventually suffer hydrogen embrittlement when temperatures exceed 80 °C and the pH is over 12. The addition of dissolved oxidizing species can extend resistance to hydrogen uptake in hot caustic solutions. Some examples of oxidizing agents are chlorate, hypochlorite, or nitrate compounds.

Corrosion Behavior of Various Metals and Alloys in Ammonium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Free-cuttring brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	3.5-40	27 (80)	...	0.05 (2) max	...	95
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Silver	P07010	...	Air must be excluded	...	Room	...	0.05 (2) max	...	9
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	...	5	80 (176)	7 d	0.003 (0.1) max	No pitting	44
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	...	10	80 (176)	7 d	0.003 (0.1) max	No pitting	44
Inconel 601	N06601	...	...	5	80 (176)	7 d	Resistant	...	64
Inconel 601	N06601	...	...	10	80 (176)	7 d	Resistant	...	64
Inconel 690	N06690	...	...	5	80 (176)	...	0.03 (1) max	...	57
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Refractory metals and alloys									
Cobalt	...	...	Static	5	25 (77)	...	0.02 (0.8)	...	54
Niobium	R04210	...	...	...	Room	...	Resistant	...	2
Ti-3Al-2.5V	...	...	...	8	150 (302)	...	Resistant	...	91
Ti-3Al-2.5V	...	...	...	28	150 (302)	...	Resistant	...	91
Titanium	...	...	...	28	26 (79)	...	0.002 (0.08)	...	1
Titanium	...	...	...	70	Boiling	...	Resistant	...	1
Titanium	...	...	...	28	26 (79)	...	0.002 (0.08)	...	1
Titanium	...	...	...	70	Boiling	...	Resistant	...	1
Titanium	...	...	...	28	Room	...	0.003 (0.12)	...	90
Titanium	...	...	...	28	100 (212)	...	Resistant	...	90
Titanium	...	...	...	8	150 (302)	...	Resistant	...	91
Titanium	...	...	...	28	150 (302)	...	Resistant	...	91
Titanium, grade 12	R53400	...	...	30	Boiling	...	Resistant	...	33
Titanium, grade 9	...	...	...	8	150 (300)	...	Resistant	...	33
Titanium, grade 9	...	...	...	28	150 (300)	...	Resistant	...	33
Zr702	R60702	...	...	28	Room to 100 (room to 212)	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	All	20 (68)	...	Resistant	...	253
301	S30100	...	...	All	Boiling	...	Resistant	...	253
302	S30200	...	...	All	20 (68)	...	Resistant	...	253
302	S30200	...	...	All	Boiling	...	Resistant	...	253
303	S30300	...	...	All	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	All	Boiling	...	Resistant	...	253
303	S30300	...	...	All	20 (68)	...	Resistant	...	253
303	S30300	...	...	All	Boiling	...	Resistant	...	253
304	S30400	...	...	...	21 (70)	...	Resistant	...	121
304	S30400	...	...	All	20 (68)	...	Resistant	...	253
304	S30400	...	...	All	Boiling	...	Resistant	...	253
304L	S30403	...	...	All	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All	Boiling	...	Resistant	...	253
316	S31600	...	...	...	21 (70)	...	Resistant	...	121
316	S31600	...	...	All	20 (68)	...	Resistant	...	253
316	S31600	...	...	All	Boiling	...	Resistant	...	253
316F	S31620	...	...	All	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All	Boiling	...	Resistant	...	253
316L	S31603	...	...	All	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All	Boiling	...	Resistant	...	253
317L	S31703	...	...	All	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All	Boiling	...	Resistant	...	253
321	S32100	...	...	All	20 (68)	...	Resistant	...	253
321	S32100	...	...	All	Boiling	...	Resistant	...	253
329	S32900	...	...	All	20 (68)	...	Resistant	...	253
329	S32900	...	...	All	Boiling	...	Resistant	...	253
347	S34700	...	...	All	20 (68)	...	Resistant	...	253
347	S34700	...	...	All	Boiling	...	Resistant	...	253
403	S40300	...	...	All	20 (68)	...	Resistant	...	253
403	S40300	...	...	All	Boiling	...	Resistant	...	253
405	S40500	...	...	All	20 (68)	...	Resistant	...	253
405	S40500	...	...	All	Boiling	...	Resistant	...	253
409	S40900	...	...	All	20 (68)	...	Resistant	...	253
409	S40900	...	...	All	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	...	21 (70)	...	Resistant	...	121
410	S41000	...	...	All	20 (68)	...	Resistant	...	253
410	S41000	...	...	All	Boiling	...	Resistant	...	253
416	S41600	...	...	All	20 (68)	...	Resistant	...	253
416	S41600	...	...	All	Boiling	...	Resistant	...	253
420	S42000	...	...	All	20 (68)	...	Resistant	...	253
420	S42000	...	...	All	Boiling	...	Resistant	...	253
430	S43000	...	...	...	(21) 70	...	Resistant	...	121
430	S43000	...	...	All	20 (68)	...	Resistant	...	253
430	S43000	...	...	All	Boiling	...	Resistant	...	253
434	S43400	...	...	All	20 (68)	...	Resistant	...	253
434	S43400	...	...	All	Boiling	...	Resistant	...	253
F51	S31803	...	...	All	20 (68)	...	Resistant	...	253

Ammonium Nitrate

Ammonium nitrate, NH_4NO_3, is a colorless crystalline solid existing in two forms. Between 16 and 32 °C, the crystals are tetragonal; between 32 and 84 °C, the crystals are rhombic. The melting point of NH_4NO_3 is 169.6 °C, and it decomposes above 210 °C. When heated, ammonium nitrate yields nitrous oxide gas. Ammonium nitrate is soluble in water, in acetic acid solutions containing ammonia, is slightly soluble in ethanol, and is moderately soluble in methanol. Ammonium nitrate is a very insensitive and stable high explosive used as a slow-burning propellant for rockets when compounded with burning rate catalysts. Although the major applications of ammonium nitrate are explosives and fertilizers, it is also used in insecticides, rust inhibitors, and pyrotechnics.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Stainless steels are excellent for service in ammonium nitrate.

Aluminum. Aluminum alloy 3003 resisted corrosion of dry ammonium nitrate at ambient temperature and of aqueous solutions of ammonium nitrate at temperatures up to 82 °C (180 °F) in laboratory tests. Aluminum alloys have been used in the production, handling, shipment, and storage of ammonium nitrate solutions prepared for fertilizer applications.

Although concentrations of up to 83% ammonium nitrate at temperatures up to 121 °C (250 °F) were acceptable, corrosion at welds can occur in hot 83% solutions in the presence of free nitric acid. The solution should therefore be maintained by agitation at a uniform pH above 6. Welded aluminum alloy 3003 tank bottoms and piping are more resistant to hot acidic conditions. Avoiding mercury contamination is a serious problem in the handling of ammonium nitrate. Aluminum alloy production and storage equipment have been used for servicing ammoniated ammonium nitrate.

Copper. Copper alloy Cu-23Zn-12Ni telephone wires were observed to suffer stress-corrosion cracking in 2 years. Laboratory tests duplicating the conditions (high humidity, positive potential, a constant load of 386 MPa, and exposure to nitrate salts including ammonium nitrate) gave the same result. Cracking occurred without an applied potential when the concentration of nitrates at the surface was high. Wires of Cu-20Ni did not crack.

Corrosion Behavior of Various Metals and Alloys in Ammonium Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum-magnesium alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	10-30	24-49 (75-120)	...	1.3 (50) min	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	20	Room	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Nickel and alloys									
Alloy 825	N08825	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89
Refractory metals and alloys									
Titanium	...	...	...	28	Boiling	...	Resistant	...	90
Titanium	...	...	...	...	100 (212)	...	Resistant	...	94
Titanium	...	...	Plus 1% HNO_3	28	Boiling	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	All	21 (70)	...	Resistant	...	121
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	Petrochemical processing (synthetic urea manufacture); slight to moderate aeration; slight to moderate agitation. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89
304	S30400	...	Petrochemical processing (synthetic urea manufacture); slight to moderate aeration; slight to moderate agitation. sensitized specimens. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89
304	S30400	...	Petroleum processing; field or pilot plant test; no aeration; slight to moderate agitation; with carbon over the standard medium. 17% free ammonia, 17% water	66	Room	715 d	0.003 (0.1) max	...	89
304	S30400	...	Research lab test; slight to moderate agitation. 21.7% free ammonia, 13.3% water	65	53 (128)	14 d	0.73 (29)	...	89

(Continued)

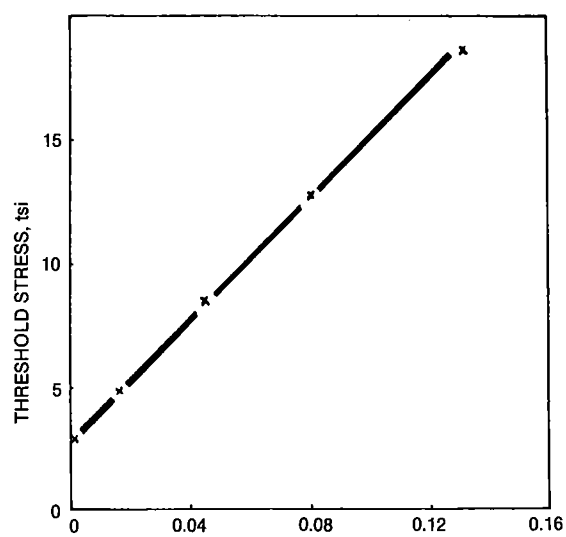
Corrosion Behavior of Various Metals and Alloys in Ammonium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Research lab test; slight to moderate agitation. 21.7% free ammonia, 13.3% water	65	53 (128)	20 d	0.33 (13)	...	89
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	All	21 (70)	...	Resistant	...	121
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	Petrochemical processing (synthetic urea manufacture); slight to moderate aeration; slight to moderate agitation. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89
316	S31600	...	Petrochemical processing (synthetic urea manufacture); slight to moderate aeration; slight to moderate agitation; sensitized specimens. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89
316	S31600	...	Petroleum processing; field or pilot plant test; no aeration; slight to moderate agitation. 17% free ammonia, 17% water	66	Room	715 d	0.003 (0.1) max	...	89
316	S31600	...	Research lab test; slight to moderate agitation. 21.7% free ammonia, 13.3% water	65	53 (128)	14 d	0.73 (29)	...	89
316	S31600	...	Research lab test; slight to moderate agitation. 21.7% free ammonia, 13.3% water	65	53 (128)	20 d	Resistant	...	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317	S31700	...	Petroleum processing; field or pilot plant test; no aeration; slight to moderate agitation. 17% free ammonia, 17% water	66	Room	715 d	0.003 (0.1) max	...	89
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Good	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	Boiling	...	Good	...	253
410	S41000	...	...	All	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Good	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Good	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253
420	S42000	...	...	Saturated	Boiling	...	Good	...	253
430	S43000	...	...	All	21 (70)	...	Resistant	...	121
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
Carpenter 20	...	...	Petrochemical processing (synthetic urea manufacture); field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Water and carbon dioxide traces, pressure 30 psig (bottom of ammonia desorber, vapors)	20	143 (290)	300 d	0.003 (0.1) max	...	89



LIVE GRAPH
Click here to view

Ferritic steels. The effect of carbon content of annealed mild steels on threshold stress for cracking in boiling 4*N* NH_4NO_3. Source: R.N. Parkins, Stress Corrosion Cracking of Low-Strength Ferritic Steels, in *The Theory of Stress Corrosion Cracking in Alloys*, J.C. Scully, Ed., North Atlantic Treaty Organization, Brussels, 1971, p 172.

Ammonium Oxalate

Ammonium oxalate $(NH_4)_2C_2O_4$, is a white solid soluble, formed by reaction of NH_4OH and oxalic acid, and then evaporating. Used as a source of oxalate; ammonium binoxalate $NH_4HC_2O_4{\cdot}H_2O$.

Corrosion Behavior of Various Metals and Alloys in Ammonium Oxalate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Good	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Questionable	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Good	...	253
403	S40300	...	...	...	Boiling	...	Questionable	...	253
405	S40500	...	...	...	20 (68)	...	Good	...	253
405	S40500	...	...	...	Boiling	...	Questionable	...	253
409	S40900	...	...	...	20 (68)	...	Good	...	253
409	S40900	...	...	...	Boiling	...	Questionable	...	253
410	S41000	...	...	...	20 (68)	...	Good	...	253
410	S41000	...	...	...	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Oxalate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	...	...	20 (68)	...	Good	...	253
416	S41600	...	...	...	Boiling	...	Questionable	...	253
420	S42000	...	...	...	20 (68)	...	Good	...	253
420	S42000	...	...	...	Boiling	...	Questionable	...	253
430	S43000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	...	Boiling	...	Questionable	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Good	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Ammonium Perchlorate

Ammonium perchlorate NH_4ClO_4, is a white solid, soluble, formed by reaction of NH_4OH and perchlorate acid, and then evaporating. Used in explosives and pyrotechnics.

Corrosion Behavior of Various Metals and Alloys in Ammonium Perchlorate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	10	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	10	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	10	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	10	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	10	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	10	Boiling	...	Questionable	Pitting	253
303	S30300	...	...	10	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	10	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	10	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	10	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	10	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	10	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	10	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	10	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	10	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	10	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	10	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	10	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	10	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	10	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Perchlorate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	10	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	10	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	10	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	10	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	10	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	10	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	10	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	10	Boiling	...	Resistant	Pitting	253
403	S40300	...	...	10	Boiling	...	Questionable	Pitting	253
405	S40500	...	...	10	Boiling	...	Questionable	Pitting	253
409	S40900	...	...	10	Boiling	...	Questionable	Pitting	253
410	S41000	...	...	10	Boiling	...	Questionable	Pitting	253
416	S41600	...	...	10	Boiling	...	Questionable	Pitting	253
420	S42000	...	...	10	Boiling	...	Questionable	Pitting	253
430	S43000	...	...	10	20 (68)	...	Resistant	Pitting	253
430	S43000	...	...	10	Boiling	...	Questionable	Pitting	253
434	S43400	...	...	10	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	10	Boiling	...	Good	Pitting	253
F51	S31803	...	...	10	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	10	Boiling	...	Resistant	Pitting	253

Ammonium Phosphate

Ammonium phosphate occurs in two forms—the monobasic, $NH_4H_2PO_4$, and dibasic, $(NH_4)_2HPO_4$, forms. It is a white crystalline solid that is soluble in water. Ammonium phosphate is a product of the reaction between ammonia and phosphoric acid. Ammonium phosphate is an important fertilizer and is used as a fire retardant.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Concentration and temperature affect the corrosion of aluminum by ammonium phosphate. The diammonium salt corrodes aluminum; therefore, the use of aluminum equipment to handle ammonium phosphate solutions should be avoided without the use of inhibitors. The monobasic salt is less corrosive than the dibasic form, and the attack rate decreases with time. In laboratory tests, aluminum alloy 3003 suffered mild attack (~10 mils/yr) in solutions of the monobasic salt with concentrations up to 28%.

Corrosion Behavior of Various Metals and Alloys in Ammonium Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum-magnesium alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Phosphate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus 3% sulfuric acid, ammonium phosphate, water	...	50-70 (122-158)	30 d	0.03 (1)	...	89
Alloy 825	N08825	...	Chemical processing; strong aeration; slight to moderate agitation. Ammonium phosphate traces in steam; ammonia, ammonium sulfate, fluorine compounds and silica traces present (agitator)	...	100-121 (212-250)	12 d	0.03 (1)	...	89
Refractory metals and alloys									
Titanium	...	...	...	10	Room	...	Resistant	...	90
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation. With carbon over the standard maximum. Ammonium monophosphate, saturated water solution	Saturated	28 (82)	150 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; lab test; no aeration; no agitation. Approx. concentration, ammonium monophosphate	40	60 (140)	22 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Ammonium monophosphate, saturated water solution	Saturated	28 (82)	150 d	0.003 (0.1) max	...	89
316	S31600	...	chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus 3% sulfuric acid, ammonium phosphate, water	...	50-70 (122-158)	30 d	0.15 (6)	...	89
316	S31600	...	Chemical processing; lab test; no aeration; no agitation. Approx. concentration, ammonium monophosphate	40	60 (140)	22 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; strong aeration; slight to moderate agitation. Ammonium phosphate traces in steam; ammonia, ammonium sulfate, fluorine compounds and silica traces present (agitator)	...	100-121 (212-250)	12 d	0.78 (31)	Slight pitting	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Ammonium monophosphate, saturated water solution	Saturated	28 (82)	150 d	0.003 (0.1) max	...	89
410	S41000	...	...	...	Room	...	Resistant	...	121

Ammonium Sulfate

Ammonium sulfate, $(NH_4)_2SO_4$, is a solid composed of colorless rhombic crystals. It has a melting point of 140 °C and is soluble in water.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 resists attack by solid ammonium sulfate under laboratory conditions of ambient temperature and 100% relative humidity. In other laboratory tests, aluminum alloy 1100 resisted concentrations of 1 to 45% ammonium sulfate solutions at ambient temperature. Aluminum alloy equipment has been used in the production and shipment of ammonium sulfate.

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Carbon and alloy steels									
Carbon steel	G10100	...	Saturated solution	...	138 (280)	14 d	1.52 (60)	...	228
Carbon steel	G10100	...	Saturated solution	...	149 (300)	14 d	2.03 (80)	...	228
Copper and alloys									
70-3- cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	Saturated solution	...	138 (280)	14 d	0.01 (0.4)	...	228
Admiralty brass	C44300	...	Saturated solution	...	149 (300)	14 d	.008 (0.3)	...	228
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Titanium	...	...	...	10	100 (212)	...	Resistant	...	90
Titanium	...	...	Plus 1% H_2SO_4	Saturated	Room	...	0.010 (0.4)	...	90
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	0.5 (20) max	...	95
Lead	L50045	...	During storage of liquid alkyl detergent. Mixing tank and crystallizer-saturated, 5% H_2SO_4 solution	...	47 (116)	...	0.125 (5) max	...	48
Lead	L50045	...	Solution plus 5% H_2SO_4	Saturated	47 (116)	...	0.025 (1)	...	48
Lead	L50045	...	Solution plus 5% H_2SO_4	Saturated	47 (116)	...	0.125 (5)	...	48
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Nickel and alloys									
Alloy 400	N04400	...	Saturated solution	...	138 (280)	14 d	.005 (0.2)	...	228
Alloy 400	N04400	...	Saturated solution	...	149 (300)	14 d	.005 (0.2)	...	228
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	7 d	Resistant	No pitting	44
Inconel 601	N06601	...	...	5	80 (176)	7 d	0.002 (0.1)	...	64
Inconel 690	N06690	...	...	5	80 (176)	...	0.03 (1) max	...	57

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel 400	N04400	...	Plus 5% H_2SO_4, in suspension tank during crystallization	Saturated	40 (106)	33 d	0.075 (3.0)	...	79
Nickel 200	N02200	...	Plus 5% H_2SO_4, in suspension tank during crystallization	Saturated	41 (106)	...	0.015 (3.0)	...	44
Nickel 200	N02200	...	Plus 5% H_2SO_4, in suspension tank during crystallization	Saturated	40 (106)	33 d	0.075 (3.0)	...	79
Refractory metals and alloys									
Titanium, grade 12	R53400	...	Saturated solution	...	138 (280)	14 d	.003 (0.1)	...	228
Titanium, grade 12	R53400	...	Saturated solution	...	149 (300)	14 d	.003 (0.1)	...	228
Zr702	R60702	...	...	5	100 (212)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	10	100 (212)	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Good	...	253
301	S30100	...	...	...	100 (212)	...	Good	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Good	...	253
302	S30200	...	...	...	100 (212)	...	Good	...	253
303	S30300	...	...	Saturated	20 (68)	...	Good	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Questionable	...	253
303	S30300	...	...	Saturated	Boiling	...	Good	...	253
303	S30300	...	...	...	100 (212)	...	Poor	...	253
303	S30300	...	...	...	100 (212)	...	Good	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	10	Boiling	...	Good	...	121
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Good	...	253
304	S30400	...	...	...	100 (212)	...	Good	...	253
304	S30400	...	Chemical processing; field of pilot plant test; slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Plus 20% ammonium sulfide 2 gal/800 gal approx. of reacted solution, 0-75% sulfuric acid, ammonia added with the acid	38	66-93 (150-200)	6 d	8.5 (340)	Severe pitting	89
304	S30400	...	Chemical processing; field of pilot plant test; slight to moderate aeration; rapid agitation. Plus 20% ammonium sulfide 2 gal/800 gal approx. of reacted solution, 0-75% sulfuric acid, ammonia added with the acid	38	66-93 (150-200)	6 d	19 (750)	Severe pitting	89
304	S30400	...	Chemical processing; slight to moderate aeration; slight to moderate agitation. Plus 0.3% sulfur dioxide, 10% sulfuric acid	36	82 (180)	25 d	0.04 (1.4)	...	89
304	S30400	...	Coal by-product processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 5% sulfuric acid, saturated water solution	...	38-47 (100-116)	33 d	0.003 (0.1) max	...	89
304	S30400	...	Mining; field or pilot plant test; no aeration; no agitation. Plus hydrogen sulfide, free ammonia trace (autoclave, vapors)	40	60-71 (140-160)	1 d	0.75 (30)	Moderate pitting	89
304	S30400	...	Mining; field or pilot plant test; no aeration; no agitation. Sensitized specimens. Plus hydrogen sulfide, free ammonia trace (autoclave, vapors)	40	60-71 (140-160)	1 d	6.0 (240)	Moderate pitting	89
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	100 (212)	...	Good	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Good	...	253
304LN	S30453	...	...	...	100 (212)	...	Good	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	10	Boiling	...	Good	...	121
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	...	100 (212)	...	Good	...	253
316	S31600	...	Chemical processing; field of pilot plant test; slight to moderate aeration; rapid agitation. Plus 20% ammonium sulfide 2 gal/800 gal approx. of reacted solution, 0-75% sulfuric acid, ammonia added with the acid	38	66-93 (150-200)	6 d	0.60 (24)	...	89
316	S31600	...	Chemical processing; slight to moderate aeration; slight to moderate agitation. Plus 0.3% sulfur dioxide, 10% sulfuric acid	36	82 (180)	25 d	0.19 (7.5)	Severe pitting	89
316	S31600	...	Mining; field or pilot plant test; no aeration; no agitation. Sensitized specimens. Plus hydrogen sulfide, free ammonia trace (autoclave, vapors)	40	60-71 (140-160)	1 d	0.75 (30)	Moderate pitting	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Good	...	253
316F	S31620	...	...	...	100 (212)	...	Good	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	100 (212)	...	Good	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	100 (212)	...	Good	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	100 (212)	...	Good	...	253
317	S31700	...	Coal by-product processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 5% sulfuric acid, saturated water solution	...	38-47 (100-116)	33 d	0.003 (0.1) max	...	89
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	100 (212)	...	Good	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	100 (212)	...	Good	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Good	...	253
321	S32100	...	...	...	100 (212)	...	Good	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	...	100 (212)	...	Good	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Good	...	253
347	S34700	...	...	...	100 (212)	...	Good	...	253
403	S40300	...	...	Saturated	20 (68)	...	Good	...	253
403	S40300	...	...	Saturated	Boiling	...	Questionable	...	253
403	S40300	...	...	...	100 (212)	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
405	S40500	...	...	Saturated	Boiling	...	Questionable	...	253
405	S40500	...	...	...	100 (212)	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Good	...	253
409	S40900	...	...	Saturated	Boiling	...	Questionable	...	253
409	S40900	...	...	...	100 (212)	...	Poor	...	253
410	S41000	...	...	10	21 (70)	...	Questionable	...	121
410	S41000	...	...	10	Boiling	...	Poor	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	Saturated	20 (68)	...	Good	...	253
410	S41000	...	...	Saturated	Boiling	...	Questionable	...	253
410	S41000	...	...	...	100 (212)	...	Poor	...	253
410	S41000	...	Plus 0.5% H_2SO_4	...	Room	...	Good	...	121
410	S41000	...	Plus 0.5% H_2SO_4	...	Room	...	Poor	...	121
416	S41600	...	...	Saturated	20 (68)	...	Good	...	253
416	S41600	...	...	Saturated	Boiling	...	Questionable	...	253
416	S41600	...	...	...	100 (212)	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Good	...	253
420	S42000	...	...	Saturated	Boiling	...	Questionable	...	253
420	S42000	...	...	...	100 (212)	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Questionable	...	121
430	S43000	...	...	10	Boiling	...	Poor	...	121
430	S43000	...	...	Saturated	20 (68)	...	Good	...	253
430	S43000	...	...	Saturated	Boiling	...	Questionable	...	253
430	S43000	...	...	...	100 (212)	...	Poor	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Good	...	253
434	S43400	...	...	...	100 (212)	...	Good	...	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	100 (212)	...	Good	...	253

Ammonium Sulfite

Colorless to white crystals that are soluble in water $(NH_4)_2SO_3H_2O$ is used both as a reducing agent and in photography. This compound is a salt that can form from the reaction of ammonia and sulfur dioxide or hydrogen sulfide. This product is frequently found in the overhead of crude distillation units and can be quite corrosive to steel equipment. Chemical corrosion inhibitors are often used to control corrosion from ammonium sulfite and other ammonium salts.

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	Saturated solution	...	138 (280)	14 d	1.27 (50)	...	228
Carbon steel	G10100	...	Saturated solution	...	149 (300)	14 d	1.27 (50)	...	228
Copper and alloys									
Admiralty brass	C44300	...	Saturated solution	...	138 (280)	14 d	0.38 (15)	...	228

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ammonium Sulfite (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Admiralty brass	C44300	...	Saturated solution	...	149 (300)	14 d	.07 (3)	...	228
Nickel and alloys									
Alloy 400	N04400	...	Saturated solution	...	138 (280)	14 d	.05 (2)	...	228
Alloy 400	N04400	...	Saturated solution	...	149 (300)	14 d	.05 (2)	...	228
Refractory metals and alloys									
Titanium, grade 12	R53400	...	Saturated solution	...	138 (280)	14 d	.003 (0.1) max	...	228
Titanium, grade 12	R53400	...	Saturated solution	...	149 (300)	14 d	.003 (0.1) max	...	228
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Questionable	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Questionable	...	253
405	S40500	...	...	Saturated	Boiling	...	Questionable	...	253
409	S40900	...	...	Saturated	Boiling	...	Questionable	...	253
410	S41000	...	...	Saturated	Boiling	...	Questionable	...	253
416	S41600	...	...	Saturated	Boiling	...	Questionable	...	253
420	S42000	...	...	Saturated	Boiling	...	Questionable	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Questionable	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Questionable	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Aniline

Aniline, $C_6H_5NH_2$, is slightly soluble in water, miscible in alcohol and ether, and turns yellow to brown in air. Aniline may be made (1) by the reduction, with iron or tin in HCl, of nitrobenzene, and (2) by the amination of chlorobenzene by heating with ammonia to a high temperature corresponding to a pressure of over 200 atmospheres in the presence of a catalyst (a mixture of cuprous chloride and oxide). Aniline is the end-point of reduction of most mononitrogen substituted benzene nuclei, as nitrobenzene beta-phenylhydroxylamine, azoxybenzene, azobenzene, hydrazobenzene. Aniline is detected by the violet coloration produced by a small amount of sodium hypochlorite.

Aniline is used as a solvent, in the preparation of compound in the manufacture of dyes and their intermediates, and in the manufacture of medicinal chemicals.

Corrosion Behavior of Various Metals and Alloys in Aniline

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Aniline Hydrochloride

Aniline hydrochloride, $C_6H_5NH_2{\cdot}HCl$, a white to greenish crystalline solid that melts at 198 °C and boils at 245 °C; soluble in water, alcohol, and chloroform; used in making dyes and in printing. Also known as aniline chloride, aniline salt.

Corrosion Behavior of Various Metals and Alloys in Aniline Hydrochloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	5	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	5	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	5	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	5	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	5	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	5	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	5	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	5	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	5	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	5	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	5	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	5	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	5	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	5	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	5	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	5	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	5	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	5	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	5	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	5	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	5	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	5	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	5	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	5	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	5	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	5	20 (68)	...	Poor	Pitting	253

Antimony Chloride

There are several different forms of antimony chloride. Antimony trichloride, $SbCl_3$ is a hygroscopic colorless crystal that is soluble in water. It is used as a mordant, in fireproofing textiles and as a chlorinating agent. Antimony pentachloride, $SbCl_5$ is a reddish yellow oily, hygroscopic liquid that decomposes in excess water. It is used in analytical testing and in dyeing.

Corrosion Behavior of Various Metals and Alloys in Antimony Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Poor	...	253
302	S30200	...	...	...	20 (68)	...	Poor	...	253
303	S30300	...	...	...	20 (68)	...	Poor	...	253
303	S30300	...	...	...	20 (68)	...	Poor	...	253
304	S30400	...	...	...	20 (68)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Antimony Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	20 (68)	...	Poor	...	253
304LN	S30453	...	...	...	20 (68)	...	Poor	...	253
316	S31600	...	...	...	20 (68)	...	Poor	...	253
316F	S31620	...	...	...	20 (68)	...	Poor	...	253
316L	S31603	...	...	...	20 (68)	...	Poor	...	253
316LN	S31653	...	...	...	20 (68)	...	Poor	...	253
316Ti	S31635	...	...	...	20 (68)	...	Poor	...	253
317L	S31703	...	...	...	20 (68)	...	Poor	...	253
317LN	S31725	...	...	...	20 (68)	...	Poor	...	253
321	S32100	...	...	...	20 (68)	...	Poor	...	253
329	S32900	...	...	...	20 (68)	...	Poor	...	253
347	S34700	...	...	...	20 (68)	...	Poor	...	253
403	S40300	...	...	...	20 (68)	...	Poor	...	253
405	S40500	...	...	...	20 (68)	...	Poor	...	253
409	S40900	...	...	...	20 (68)	...	Poor	...	253
410	S41000	...	...	...	20 (68)	...	Poor	...	253
416	S41600	...	...	...	20 (68)	...	Poor	...	253
420	S42000	...	...	...	20 (68)	...	Poor	...	253
430	S43000	...	...	...	20 (68)	...	Poor	...	253
434	S43400	...	...	...	20 (68)	...	Poor	...	253
F51	S31803	...	...	...	20 (68)	...	Poor	...	253

Aqua Regia

Aqua regia, also known as nitrohydrochloric acid and chloroazoatic acid, is a fuming, volatile liquid that is made by mixing three parts concentrated hydrochloric acid with one part concentrated nitric acid. It is very corrosive with a suffocating odor and reacts with all metals. Aqua regia typically reacts by oxidizing the metal to a metallic ion and reducing the nitric acid to nitric oxide. Its reaction with silver produces silver chloride. Aqua regia dissolves the common metallic oxides and hydroxides, the ignited oxides of tin, aluminum, chromium, and iron, and the higher oxides of lead, cobalt, nickel, and manganese. It is used for testing gold and platinum.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests show aqua regia to be very corrosive to all aluminum alloys.

Niobium. Niobium has been reported to have a corrosion rate of less than 0.025 mm/yr (1 mil/yr) in aqua regia at 55 °C (130 °F).

Gold. Aqua regia rapidly attacks gold.

Iridium. Iridium resists cold and boiling aqua regia, but may be dissolved by aqua regia under pressure by heating to 250 to 300 °C (480 to 570 °F).

Platinum. Platinum is attacked by aqua regia and mixtures of hydrochloric acid and oxidizing agents.

Rhodium. Rhodium is unattacked by aqua regia at 100 °C (212 °F) in either wrought or cast form.

Ruthenium. Ruthenium is the most chemically resistant of the platinum metals and is not attacked or dissolved by either hot or cold aqua regia.

Tantalum. Tantalum is not attacked by aqua regia at ordinary temperatures.

Zirconium. Aqua regia attacks zirconium.

Hafnium. Hafnium is dissolved by aqua regia, and with the addition of small amounts of soluble fluoride salts, the reaction with other acids is appreciably increased.

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Corrosion Behavior of Various Metals and Alloys in Aqua Regia

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	...	...	Room	...	Poor	...	8
Iridium	...	...	...	...	Room-boiling	...	Resistant	...	29
Osmium	...	...	...	...	Boiling	...	Poor	...	17
Palladium	P03980	...	...	...	Room	...	Poor	...	17
Rhodium	P05990	...	...	...	Boiling	...	Resistant	...	29
Ruthenium	...	...	...	...	100 (212)	...	Resistant	...	18
Silver	P07010	...	Attack will occur whenever silver chloride film is ruptured	...	Room	...	Poor	...	4
Silver	P07010	...	Potential dissolution. Attack will accur whenever silver chloride film is ruptured	...	Room	...	...	...	4
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Tantalum	R05210	...	...	...	25 (78)	...	Resistant	...	42
Ti-3Al-2.5V, grade 9	...	...	...	...	Boiling	...	1.27 (51)	...	91
Ti-3Al-2.5V, grade 9	...	...	...	...	Room	...	0.01 (0.6)	...	91
Titanium	...	...	...	...	Room	...	Resistant	...	90
Titanium	...	...	...	...	80 (176)	...	0.86 (34.4)	...	90
Titanium	...	...	...	...	Boiling	...	1.12 (44.8)	...	90
Titanium	...	...	...	...	Boiling	...	1.1 (44)	...	91
Titanium	...	...	...	...	Room	...	Resistant	...	91
Titanium, grade 12	R53400	...	...	...	Boiling	...	0.61 (24.4)	...	33
Titanium, grade 7	R52400	...	...	...	Boiling	...	0.12 (44.8)	...	33
Titanium, grade 9	...	...	...	...	Boiling	...	1.29 (51.6)	...	33
Titanium, grade 9	...	...	...	...	25 (75)	...	0.015 (0.6)	...	33
Zirconium	R60701	...	...	...	Room	...	Poor	...	36
Zirconium	R60702	...	3 parts HCl/1 part HNO_3	3:1	Room	...	1.3 (50) min	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	...	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	...	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	...	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	...	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Poor	Pitting	253

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Arsenic Acid

Arsenic acid, $H_3AsO_4 \cdot \frac{1}{2}H_2O$, white translucent crystals, soluble in water and alcohol; used in insecticides, glassmaking, and defoliants. Also known as orthoarsenic acid.

Corrosion Behavior of Various Metals and Alloys in Arsenic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Resistant	...	253
405	S40500	...	...	...	...	...	Resistant	...	253
409	S40900	...	...	...	...	...	Resistant	...	253
410	S41000	...	...	...	...	...	Resistant	...	253
416	S41600	...	...	...	...	...	Resistant	...	253
420	S42000	...	...	...	...	...	Resistant	...	253
430	S43000	...	...	...	...	...	Resistant	...	253
434	S43400	...	...	...	...	...	Resistant	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253

Atmospheric Environments

Atmospheres are often classified as being rural, industrial, or marine in nature, but this is an oversimplification. For example, there are locations along the seacoast that have heavy industrial pollution in the atmosphere, and they are both marine and industrial. Furthermore, two decidedly rural environments can differ widely in average yearly temperature and rainfall and can therefore have considerably different corrosive tendencies. Industrial expansion into formerly rural areas can easily change the aggressiveness of a particular location. Finally, long-term trends in the environment, such as changes in rainfall patterns, mean temperature, and perhaps acid rain, can make extrapolations from past behavior less reliable. Other factors that limit the usefulness of atmospheric exposure data are the general nonlinearity of weight loss due to

corrosion with time and the fact that most atmospheric corrosion data are presented as an average over the entire test panel surface. Most atmospheric exposure data for steels show a decrease in the rate of attack with time of exposure so that extrapolations of such data to times longer than those covered by the exposure data can lead to an over design in cross section. Finally, in many cases, the average weight loss per unit area is of less concern than the time to perforation. This factor is more related to localized attack, which can be masked by the averaging of data, as is done in weight loss determinations.

Given these variables, the design engineer is well justified in using atmospheric-corrosion data as more indicative than quantitative. Perhaps most important, it should be remembered that it is impossible to describe either the extent or rate of corrosion under atmospheric conditions with a single parameter, which is what much of the reported corrosion data persist in doing. When the results of a several-year exposure test are condensed to a single value, such as the average loss per year or the total loss for the exposure period, one cannot estimate the values of the kinetic parameters governing the system. Without the values of these parameters, extrapolation of results to longer exposure periods becomes quite unreliable. When good estimates for the kinetic parameters are available, extrapolations to 7- or 8-year performance from 1- to 2-year data have been found to agree within 5% of observed performance.

Rainwater has been recognized as a potential source of corrosive agents that can be inadvertently transported into a protective environment and cause deterioration of susceptible materials.

Inadvertent admission of atmospheric moisture into silos and launch control centers of missile systems has been cited as the cause of most of the general corrosion problems associated with the various metals contained in these structures. Despite the fact that corrosion problems have been encountered in missile silos, the maintenance of a humidity-controlled environment has generally been effective in protecting most components from corrosion. For example, one manufacturer has not found a single case of corrosion of beryllium components in rocket thrusters during periodic examinations of all operational units through years of continued service. These components were maintained under humidity-controlled conditions.

One study demonstrated the noncorroding nature of pure water vapor when the beryllium surface is uncontaminated and free of exposed Be_2C inclusions. Polished, bare specimen coupons were subjected to an atmosphere of 95% relative humidity at 40 °C (100 °F) for 30 days with no apparent corrosive attack. Neither microscopic examination nor weight gain measurements indicated corrosive attack on any of the specimens.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum

Most aluminum alloys have been shown to be resistant to atmospheric corrosion in laboratory tests and have been used widely in structural and architectural applications. The A.O. Smith Building in Milwaukee (completed in 1930) may have been the forerunner of aluminum curtain wall construction. When examined in 1962, a 6.35-mm (250-mil) cast panel from this building showed an average measured depth of attack of 0.053 mm (2.1 mils). Aluminum shingles for residential roofing were first marketed in 1928. One such roof made of 0.508-mm (20-mil) 3003 alloy sheet, when examined after 30 years of exposure to an industrial atmosphere, exhibited an average depth of corrosion attack of 0.076 mm (3.0 mils). Since 1930, aluminum roofing and siding have been used in many applications throughout the world. Alclad aluminum roofing and siding have been employed in a wide variety of industrial atmospheres. In such applications, corrosion is arrested at the cladding/core interface due to cathodic protection by the 1% Zn aluminum alloy cladding. Large quantities of these alclad aluminum sheet products have been used in port facilities throughout the United States in applications such as transit sheds, storage buildings, and the like. Aluminum has been used for electrical power cables since early in this century. One of the first stranded aluminum power cables exhibited an average measured depth of corrosion attack of 0.109 mm (4.3 mils) after 51 years of service near Hartford, Connecticut. Most aluminum alloys have excellent resistance to atmospheric corrosion (often called weathering), and in many outdoor applications, such alloys do not require shelter, protective coatings, or maintenance. Aluminum alloy products that have no external protection and therefore depend critically on this property include electrical conductors, outdoor lighting poles, ladders, and bridge railings. Such products often retain a bright metallic appearance for many years, but their surfaces may become dull, gray, or even black as a result of pollutant accumulation. Corrosion of most aluminum alloys by weathering is restricted to mild surface roughening by shallow pitting, with no general thinning. However, such attack is more severe for alloys with higher copper contents, and such alloys are seldom used in outdoor applications without protection. Corrosivity of the atmosphere to metals varies greatly from one geographic location to another, depending on such weather factors as wind direction, precipitation and temperature changes, amount and type of urban and industrial pollutants, and proximity to natural bodies of water. Service life may also be affected by the design of the structure if weather conditions cause repeated moisture condensation in unsealed crevices or in channels with no provision for drainage. Laboratory exposure tests, such as salt spray, total-immersion tests, provide useful comparative information, but have limited value for predicting actual service performance and sometimes exaggerate differences among alloys that are negligible under atmospheric conditions. Consequently, extensive long-term evaluations of the effects of exposure in different industrial, chemical, seacoast, tropical, and rural environments have been made.

Effect of Exposure Time. A very important characteristic of weathering of aluminum and of corrosion of aluminum under many other environmental conditions is that corrosion rate decreases with time to a relatively low, steady-state rate. This deceleration of corrosion occurs regardless of alloy composition, type of environment, or the parameter by which the corrosion is measured. However, loss in tensile strength, which is influenced somewhat by pit acuity and distribution, but is basically a result of loss of effective cross section, decelerates more gradually than depth of attack.

The decrease in rate of penetration of corrosion is dramatic. In general, rate of attack at discrete locations, which is initially about 0.1 mm/yr (4 mils/yr), decreases to much lower and nearly constant rates within a period of about 6 months to 2 years. For the deepest pits, the maximum rate after about 2 years does not exceed about 0.003 mm/yr (0.11 mil/yr) for severe seacoast locations and may be as low as 0.0008 mm/yr (0.03 mil/yr) in rural or arid climates.

Wrought Alloys. Aluminum alloy sheet was tested in desert, rural, seacoast, and industrial exposures. Results after 20 years of exposure were as follows. In aggressive (seacoast and industrial) environments, the bare (nonalclad) heat treated alloys—2017-T3 and, to a lesser extent, 6051-T4—exhibited more severe corrosion and greater resulting loss in tensile strength than the non-heat-treatable alloys. Alclad 2017-T3, although as severely corroded as the non-heat-treatable materials, did not show measurable loss in strength; in fact, some specimens of this alloy were 2 to 3% higher in strength after 20 years because of long-term natural aging.

Data from these and other weathering programs demonstrate that differences in resistance to weathering among non-heat-treatable alloys are not great, that alclad products retain their strength well because corrosion penetration is confined to the cladding layer, and that corrosion and resulting strength loss tend to be greater for bare (nonalclad) heat-treatable 2*xxx* and 7*xxx* series alloys.

Casting Alloys. The testing program that was the source of the strength change data for wrought alloys also provided weathering data for casting alloys exposed for the same period and at the same sites. Specimens were separately sand-cast and permanent mold cast tensile bars, each with a reduced section 12.7 mm (0.5 in.) in diameter. Alloys with relatively high copper contents, such as 295.0-T6, 208.0-F, 319.0-T6, and 319.0-T61, showed the greatest losses. Alloys of the zinc-containing 7*xxx* series generally exhibited larger strength losses than alloys having low zinc or copper contents. In all cases, as for wrought materials, severity of corrosion varied widely, depending on environmental conditions.

Cast Irons

Atmospheric corrosion of cast irons is basically of interest only for unalloyed and low-alloy cast irons. Atmospheric corrosion rates are determined by the relative humidity and the presence of various gases and solid particles in the air. The high humidity, sulfur dioxide (SO_2) or similar compounds found in many industrialized areas, and chlorides found in marine atmospheres increase the rate of attack on cast irons.

Cast irons typically exhibit very low corrosion rates in industrial environments—generally under 0.13 mm/yr (5 mils/yr)—and the cast irons are usually found to corrode at lower rates than steel structures in the same environment. White case irons show the lowest rate of corrosion of the unalloyed materials. Pearlitic irons are generally more resistant than ferritic irons to atmospheric corrosion.

In marine atmospheres, unalloyed cast irons also exhibit relatively low rates of corrosion. Low alloy additions are sometimes made to improve corrosion resistance further. Higher alloy additions are even more beneficial, but are rarely warranted. Gray iron offers some added resistance over ductile iron in marine atmospheres.

Carbon Steels

The effects of various atmospheres on the corrosion rates of cold-rolled carbon steels were determined in a series of weight-loss measurements performed after 2 years of exposure. The most startling feature of this study was the extreme range of corrosion rates occurring at the various test sites. For example, Geleta Point Beach, Panama, was found to be more than 450 times as aggressive as a site at Normal Wells, N.W.T., Canada. This difference in corrosion rate is easily greater than any effect that can be produced by small changes in composition of the steel. Again, this underscores the fact that in dealing with the corrosion of carbon steels the alteration of design or environmental factors is usually more effective than changing the grade of steel.

Further examination shows that the marine environments tended to be near the aggressive end of the list and that cold environments were generally less aggressive than warm sites. The average yearly temperature cannot, in general, be isolated from the moisture effect, because most of the more tropical exposure sites are also in regions with high humidity. One exception is arid Phoenix, Arizona.

Because carbon steels are by definition not very highly alloyed, it is not surprising that most grades do not exhibit large differences in atmospheric corrosion rates. Nevertheless, alloying can make changes in the atmospheric corrosion rate of carbon steel. The elements generally found to be most beneficial in this regard are copper, nickel, silicon, chromium, and phosphorus. Of these, the most striking example is that of copper; increases from 0.01 to 0.05% have been shown to decrease the corrosion rate by a factor of two to three. Additions of the above elements in combination are generally more effective than when added singly, although the effects are not additive. The effectiveness of these elements in retarding corrosion also appears to depend on the corrosive environment, with the most benefit appearing in industrial atmospheres.

Alloy Steels

A study of 270 alloy steels was performed in which experimental heats of steel involving systematic combinations of chromium, copper, nickel, silicon, and phosphorus were tested to determine the individual and joint contributions of these elements to corrosion resistance. The data showed that long-term atmospheric corrosion of carbon steels can be reduced by small additions of copper, that additions of nickel are also effective, and that chromium in sufficient amounts is helpful if copper is present. The maximum resistance to corrosion was obtained in this study when alloy contents were raised to their highest levels.

Some of the results obtained in industrial environments were as follows. The corrosion rate for carbon steel becomes constant after about 5 years. The corrosion rate for copper steel levels off to a constant value after about 3 years. High-strength low-alloy steel, which contains several alloying elements, exhibits a constant rate after approximately 2 years, and corrosion of this steel eventually ceases. ASTM low-alloy steels A242, A588, A514, and A517 exhibit significantly better performance than either carbon steel or structural copper steel.

Although the results given above provide good estimates of average corrosion behavior, corrosion rates can increase significantly in severe environments. This study does, however, demonstrate the effectiveness of increased alloy content on corrosion resistance.

Stainless Steels

The atmospheric contaminants most often responsible for the rusting of structural stainless steels are chlorides and metallic iron dust. Chloride contamination may originate from the calcium chloride ($CaCl_2$) used to make concrete or from exposure in marine or industrial locations. Iron contamination may occur during fabrication or erection of the structure. Contamination should be minimized, if possible.

The corrosivity of different atmospheric exposures can vary greatly and can dictate application of different grades of stainless steel. Rural atmospheres, uncontaminated by industrial fumes or coastal salt, are extremely mild in terms of corrosivity for stainless steel, even in areas of high humidity. Industrial or marine environments can be considerably more severe.

Resistance to staining can depend on the specific exposure. For example, several 300-series stainless steels showed no rust after long-term exposures in New York City. On the other hand, staining was observed

after much shorter exposures at Niagara Falls in a severe industrial-chemical environment near plants producing chlorine or HCl.

Although marine environments can be severe, stainless steels often provide good resistance. In a study comparing several AISI 300-series stainless steels after a 15-year exposure to a marine atmosphere 250 m (800 ft) from the ocean at Kure Beach, North Carolina, materials containing molybdenum exhibited only extremely slight rust stain, and all grades were easily cleaned to reveal a bright surface. Type 304 stainless steel may provide satisfactory resistance in many marine applications, but more highly alloyed grades are often selected when the stainless is sheltered from washing by the weather and is not cleaned regularly.

Type 302 and 304 stainless steels have had many successful architectural applications. Type 430 stainless steel has been used in many locations, but there have been problems. For example, type 430 stainless steel rusted in sheltered areas after only a few months of exposure in an industrial environment. The type 430 stainless steel was replaced by type 302, which provided satisfactory service. In more aggressive environments, such as marine or severely contaminated atmospheres, type 316 stainless steel is especially useful.

Stress-corrosion cracking is generally not a concern when austenitic or ferritic stainless steels are used in atmospheric exposures. Several austenitic stainless steels were exposed to a marine atmosphere at Kure Beach, North Carolina. Annealed and quarter-hard wrought AISI types, 201, 301, 302, 304, and 316 stainless steels were not susceptible to stress-corrosion cracking. In the as-welded condition, only type 301 stainless steel experienced failure. Following sensitization at 650 °C (1200 °F) for 1.5 h and furnace cooling, failures were obtained only for materials with carbon contents of 0.043% or more.

Stress-corrosion cracking must be considered when quench-hardened martensitic stainless steels or precipitation-hardening grades are used in marine environments or in industrial locations where chlorides are present. Several hardenable stainless grades were exposed as U-bends 25 m (80 ft) from the ocean at Kure Beach, North Carolina. Most samples were cut longitudinally, and two alloys received different heat treatments to produce different hardness or strength levels. The results of the study indicated that Custom 450 stainless and stainless alloy 355 resisted cracking. Stainless alloy 355 failed in this type of test when fully hardened; resistance was imparted by the 540 °C (1000 °F) temper. Precipitation-hardenable grades are expected to exhibit improved corrosion resistance when higher aging temperatures (lower strengths) are used.

Resistance to stress-corrosion cracking is of particular interest in the selection of high-strength stainless steels for fastener applications. Cracking of high-strength fasteners is possible and often results from hydrogen generation due to corrosion or contact with a less noble material, such as aluminum. Resistance to stress-corrosion cracking can be improved by optimizing the heat treatment, as noted above.

Fasteners for atmospheric exposure have been fabricated from a wide variety of alloys. Type 430 and unhardened type 410 stainless steels have been used when moderate corrosion resistance is required in a lower strength material. Better-than-average corrosion resistance has been obtained by using type 305 and Custom Flo 302HQ stainless steels when lower strength is acceptable.

Coppers

Copper and copper alloys are suitable for atmospheric exposure. Copper and copper alloys resist corrosion by industrial, marine, and rural atmospheres, except atmospheres containing NH_3 or certain other agents where stress-corrosion cracking has been observed in high-zinc alloys (>20% Zn). The copper metals most widely used in atmospheric exposure are C11000, C22000, C23000, C38500, and C75200. Alloy C11000 is an effective material for roofing, flashings, gutters, and downspouts. The severity of the corrosion attack in marine atmospheres is somewhat less than that in industrial atmospheres, but greater than that in rural atmospheres. However, these rates decrease with time.

Individual differences in corrosion rates do exist between alloys, but these differences are frequently less than the differences caused by environmental factors. Thus, it becomes possible to classify the corrosion behavior of copper alloys in a marine atmosphere into two general categories: those alloys that corrode at a moderate rate and include high-copper alloys, silicon bronze, and tin bronze; and those alloys that corrode at a lower rate and include brass, aluminum bronze, nickel silver, and copper nickel.

Environmental factors can cause the median thickness loss to vary by as much as 50% or more in a few extreme cases. Those environmental factors that tend to accelerate metal loss include high humidity, high temperatures (either ambient or due to solar radiation), proximity to the ocean, long times of wetness, and the presence of pollutants in the atmosphere. The converse of these conditions would tend to retard metal loss.

Metallurgical factors can also affect metal loss. Within a given alloy family, those with a higher alloy content tend to corrode at a lower rate. Surface finish also plays a role in that a highly polished metal will corrode slower than one with a rougher surface. Finally design details can affect corrosion behavior. For example, designs that allow the collections and stagnations of rainwater will often exhibit wastage rates in the puddle areas that are more typical of those encountered in seawater immersions.

Certain copper alloys are susceptible to various types of localized corrosion that can greatly affect their utility in a marine atmosphere. Brasses and nickel silvers containing more than 15% Zn can suffer from dealloying. The extent of this attack is greater on alloys that contain higher proportions of zinc. In addition, these same alloys are subject to stress-corrosion cracking in the presence of small quantities of NH_3 or other gaseous pollutants. Many natural environments contain pollutants that, in the presence of moisture, may cause stress-corrosion problems. Sulfur dioxide, oxides of nitrogen, and NH_3 are known to induce stress-corrosion cracking of some copper alloys. Chlorides may also cause problems. Inhibited grades of these alloys are available that resist dealloying but are susceptible to stress-corrosion cracking.

Alloys containing large amounts of manganese tend to be somewhat prone to pitting in marine atmospheres, as are the cobalt-containing beryllium-coppers. A tendency toward intergranular corrosion has been observed in silicon bronzes and aluminum brass, but its occurrence is somewhat sporadic.

On the whole, however, even under somewhat adverse conditions, the average thickness losses for copper alloys in a marine atmosphere tend to be very slight, typically under 50 m. Thus, copper alloys can be safely specified for applications requiring long-term durability in a marine atmosphere. Design considerations for the atmospheric use of the copper alloys include allowance for free drainage of structures, the possibility of staining from runoff water, and the use of smooth or polished surfaces.

Copper-Tin Alloys. Early studies were conducted on Cu-6.3Sn-0.08P wire and Cu-6.3Sn-0.08P-0.5Zn sheet in rural, suburban, urban, indus-

trial, and marine environments for 1 year. The bronze samples ranked consistently high among the materials tested.

In a study involving exposure of screen wire cloth at four sites for up to 9 years, Cu-2Sn bronze was found to exhibit the lowest strength losses at all sites from a group of alloys that included brasses, aluminum bronze, and nickel-copper. Outstanding corrosion resistance of a Cu-2Sn bronze exposed to sulfur-bearing gases in railway tunnels was also reported.

Another investigation compared the behavior of five stainless steels and a low-alloy steel with that of a Cu-4.38Sn-0.36P bronze exposed at tropical inland and seacoast sites for 8 years. The coastal site was more aggressive toward the bronze, which showed higher weight losses at both sites than the stainless steels, but the low-alloy steel was more severely attacked. However, the bronze was free of pitting and suffered no loss in strength, which was not the case with some of the stainless steels. These researchers summarized the results of 16-year exposures on three tin-containing alloys (Cu-4.38Sn-0.36P, Cu-39Zn-0.84Sn, and Cu-40Zn-1Fe-0.65Sn) exposed at marine, inland semirural, and two tropical sites. In general, the copper alloys resisted corrosion in the tropical zones, although less so at coastal sites compared to inland sites. The tin-containing alloys were as good as, or slightly superior to, the other alloys.

More recent work by the same investigators included previous data plus additional information on the following cast bronzes: Cu-5Sn-5Pb-5Zn, Cu-6Sn-2Pb-3Zn-1Ni, Cu-9Sn-3Zn-1Ni, and Cu-3Sn-2Zn-6Ni. The conclusions were much the same as before. The later work included a study of the effect of coupling phosphor bronze to equal areas of numerous other metals, and this work indicated that the coastal sites were 4 to 8 times more aggressive than the inland sites. Evaluation of the effect of corrosion on the solderability of a Cu-2Sn-9Ni alloy was reported by workers at Bell Telephone, who found this material to be superior to both nickel silver and an 8% Sn phosphor bronze.

Alloys in the Cu-Sn-Al system were evaluated, and those alloys containing at least 5% each of tin and aluminum were found to have good corrosion resistance in rural, urban, and industrial environments. The most promising material was Cu-5Sn-7Al. Another researcher noted that such alloys could be brittle, but that the addition of 1% Fe and 1% Mn overcame this difficulty without detracting from the corrosion resistance of the alloy.

Iridium

Iridium alloys containing up to 60% Rh have been proposed for high-temperature thermocouples. The couple iridium versus Ir-40Rh is regarded as one of the most satisfactory for use in oxidizing atmospheres at temperatures as high as 2100 °C (3810 °F).

Lead

In most of its forms, lead exhibits consistent durability in all types of atmospheric exposure, including industrial, rural, and marine. These three atmospheric environments are distinct because each involves different factors that promote corrosion. In rural areas, which are relatively free of pollutants, the only important environmental factors influencing corrosion rate are humidity, rainfall, and air flow. However, near or on the sea, chlorides entrained in marine air often exert a strong effect on corrosivity. In industrial environments, sulfur oxide gases and the minerals in solid emissions change the patterns of corrosion behavior considerably. However, the protective films that form on lead and its alloys are so effective that corrosion is insignificant in most natural atmospheres. The extent of this protection is demonstrated by the survival of lead roofing and auxiliary products after hundreds of years of atmospheric exposure. In fact, the metal is preserved permanently if these films are not damaged.

Antimonial lead, such as UNS 52760 (Pb-2.75Sb-0.2Sn-0.18As-0.075Cu), exhibits approximately the same corrosion rate in atmospheric environments as chemical lead (99.9% commercial-purity lead). However, the greater hardness, strength, and resistance to creep of antimonial lead often make it more desirable for use in specific chemical and architectural applications. The ability of some antimonial leads to retain this greater mechanical strength in atmospheric environments has been demonstrated in exposure tests in which sheets containing 4% Sb and smaller amounts of arsenic and tin were placed in semirestricted positions for 3 years. They showed less tendency to buckle than chemical lead, indicating that their greater resistance to creep had been retained.

Magnesium

A clean, unprotected magnesium alloy surface exposed to indoor or outdoor atmospheres free from salt spray will develop a gray film that protects the metal from corrosion while causing only negligible losses in mechanical properties. Chlorides, sulfates, and foreign materials that hold moisture on the surface can promote corrosion and pitting of some alloys unless the metal is protected by properly applied coatings.

The surface film that ordinarily forms on magnesium alloys exposed to the atmosphere gives limited protection from further attack. Unprotected magnesium and magnesium alloy parts are resistant to rural atmospheres and moderately resistant to industrial and mild marine atmospheres, provided they do not contain joints or recesses that entrap water in association with an active galvanic couple.

Corrosion of magnesium alloys increases with relative humidity. At 9.5% humidity, neither pure magnesium nor any of its alloys exhibit evidence of surface corrosion after 18 months. At 30% humidity, only minor corrosion may occur. At 80% humidity, the surface may exhibit considerable corrosion. In marine atmospheres heavily loaded with salt spray, magnesium alloys require protection for prolonged survival.

Indoor Atmospheres. Before the computer age, reaction of magnesium alloys with indoor atmospheres was of concern primarily from the standpoint of appearance, not function. The widespread introduction of magnesium die casting into the computer disk drive environment has imposed strict new standards of surface stability on the metal because of the need to maintain a clean particle-free atmosphere at the disk/head interface. The corrosion of magnesium alloys in indoor atmospheres increases with relative humidity. At relative humidities up to about 90%, corrosion is very minor, as humidity increases beyond this level, heavier tarnish films develop.

Nickel

Nickel and nickel-base alloys have very good resistance to atmospheric corrosion. Corrosion rates are typically less than 0.0025 mm/yr (0.1 mil/yr), with varying degrees of surface discoloration depending on the alloy. Nickel 200 will become dull and acquire a thin adherent corrosion film, which is usually a sulfate. A greater tarnish will result in industrial sulfur-containing atmospheres than in rural or marine atmospheres.

Corrosion of alloy 400 is negligible in all types of atmospheres, although a thin gray-green patina will develop. In sulfurous atmospheres, a brown patina may be produced. Because of its low corrosion rate and pleasing patina, alloy 400 has been used for architectural service, such as roofs, gutter, and flashings, and for outdoor sculpture.

Nickel alloys containing chromium and iron, such as alloys 600 and 800, also have very good atmospheric corrosion resistance, but may develop a slight tarnish after prolonged exposure, especially in industrial atmospheres. Nickel-chromium-molybdenum materials such as alloys 825, 625, G, C-276 and C-22 develop very thin and protective passive oxide films that prevent even significant tarnishing. A mirror finish can be maintained after extended exposure to the atmosphere.

Although alloy 400 has been used for atmospheric service in the past, atmospheric exposures requiring nickel alloys are now relatively infrequent. Less costly low-alloy stainless steels or plated materials are normally used.

Palladium

Palladium alloys containing more than 10% Au are resistant to tarnish by industrial sulfur-bearing environments, and those with more than 20% Au are resistant to HNO_3 and HCl. Palladium alloys with 10% of either rhodium or iridium are untarnished by industrial sulfur-bearing atmospheres.

Platinum

Platinum is one of the few metals that is unaffected by atmospheric exposure, even in sulfur-bearing industrial atmospheres. Alloys containing more than 60% Ag are tarnished by exposures to industrial atmospheres.

Tin

In clean dry air, tin retains a bright appearance for many days. In one study, a light dulling was observed after 100 days, and noticeable, faint yellow-gray tarnish film was seen after 150 days. However, it was also reported that the reflectivity of tin remains practically unchanged over long periods when the tin is washed with soap and water. Thus, at ordinary temperatures, the surface oxide film on tin is very thin and exhibits a very slow rate of growth. The rate of oxidation increases with temperature. Above 190 °C (375 °F), a film thickness sufficient to produce interference colors is reportedly produced in a few hours; at 210 °C (419 °F), a film thickness sufficient to produce interference colors is reportedly produced in a few hours; at 210 °C (410 °F), this film thickness is produced in 20 min.

Pewter. By definition, modern pewter is an alloy that contains 90 to 90% Sn, 1 to 8% Sb, 0.25 to 3% Cu, and a maximum of 0.05% Pb and As. Material that conforms to these standards has about the same degree of corrosion resistance to ordinary atmospheres as pure tin. Alloys within this range are widely used for decorative items, containers, and flatware. Indoors, they retain a bright, white luster in the same manner as pure tin. Because contamination from fabrication residues can deteriorate the protective oxide, care should be exercised in finishing to remove residues from soldering fluxes and cleaning solutions.

In years past, pewter alloys contained lead in sufficient quantities to affect its corrosion resistance significantly, for example, by producing a dark patina during atmospheric exposure. Modern pewter can be chemically treated to reproduce this patina.

Soft Solders. Even small additions of lead to tin impair the retention of its bright reflective surface in common atmospheres. With increasing lead content, the appearance of soldered joints becomes increasingly dull, like that of lead. However, destructive corrosion (except effects from flux residues) is highly unusual. On rare occasions, within enclosed spaces, condensed pure water may extract lead, but more common causes of trouble are volatile organic acids. Acetic acid (CH_3COOH) vapors from wood or insulating materials and formic acid (HCOOH) or other acids that may come from insulating materials may attack lead-containing solders to produce a white incrustation and cause serious destruction of metal.

Contact of solder with other metals can impose a serious risk in conditions of exposure to sea spray or where pockets or crevices can trap moisture or flux residues. In most atmospheric conditions, the formation of lead sulfate ($PbSO_4$) protects the solder. However, in chloride pollution conditions, nickel, copper, and their alloys are likely to be cathodic to solder. Zinc tends to be strongly anodic to soft solders, but correctly designed zinc roof coverings appear to suffer no deterioration at the soldered joints.

Zinc

It is generally accepted that the corrosion rate of zinc is low; it ranges from 0.13 µm/yr (0.005 mil/yr) in more moist industrial atmospheres. Zinc is more corrosion resistant than steel in most natural atmospheres, the exceptions being ventilated indoor atmospheres where the corrosion of both steel and zinc is extremely low and certain highly corrosive industrial atmospheres. For example, in seacoast atmospheres, the corrosion rate of zinc is about 1/25 that of steel. For both steel and zinc, corrosion rates vary significantly among different locations and climates.

Indoor Exposure. Zinc corrodes very little in ordinary indoor atmospheres of moderate relative humidity. In general, a tarnish film begins to form at spots where dust particles are present on the surface; the film then develops slowly. This attack may be a function of the percentage of relative humidity at which the particles absorb moisture from the air. However, moisture has little effect on the tarnish formation up to 70% relative humidity. The degree of corrosion is related to the relative humidity at and above this point, because the zinc corrosion products absorb enough moisture to stimulate the attack to a perceptible rate.

Rapid corrosion can occur where the temperature decreases and where visible moisture that condenses on the metal dries slowly. This is related to the ease with which such thin moisture films maintain a high oxygen content because of the small volume of water and large water/air interface area. Considerably accelerated corrosion can then take place with the formation of a film that is too thick. Atmospheres inside industrial buildings can be corrosive, particularly where heated moisture and gases, such as SO_2, condense near a cool room.

Atmospheric Exposure. Several atmospheric exposure programs have been conducted throughout the world to obtain corrosion rate data for zinc exposed to representative natural atmospheres. These programs have provided quantitative evidence of the excellent resistance of zinc over a wide range of atmospheric conditions. Although there is considerable spread in terms of percentage in the corrosion rates observed, the actual corrosion rate rarely exceeded about 8 µm/yr (0.3 mil/yr) in average metal loss, even under the more severe conditions. This is well within all standards of acceptable corrosion performance.

The amount of zinc corrosion with increasing time of exposure depends on the type of atmosphere. In semi-industrial and rural atmospheres, the corrosion rate is approximately constant. On the other hand, the corrosion rate decreases with time in marine atmospheres and increases with time in industrial atmospheres. In all cases, the yearly change in corrosion rate decreases with time and approaches a steady rate. The equilibrium corrosion rate also depends on the environment. The rate in a rural atmosphere is only about one-fifth that in an industrial atmosphere and one-third that in a marine atmosphere.

Although neither iron nor zinc corrodes appreciably in the rural climate of Normal Wells, Northwest Territory (N.W.T.), the atmospheres at the Geleta Point Beach site in the Panama Canal zone appears to be the most corrosive to these metals. Corrosivity can vary appreciably over very short distances. For example, a comparison of the corrosion rates for two Kure Beach, North Carolina, sites shows that the corrosion rate for zinc at the 25 m (80 ft) site is roughly three times that of the 250 m (800 ft) site, although the sites were only 225 m (720 ft) apart.

The corrosion rate data for steel in the same atmosphere show that steel, in general, corrodes at a greater rate than zinc in all atmospheres. The progress of corrosion with time, however, may be quite different for the two metals; therefore, direct comparison of corrosion rates should specify the duration of exposure for which the comparison are made. For example, the corrosion rate of zinc decreases with time in a severe seacoast environment (Kure Beach: 25 m, or 80 ft, site), but that of steel increases with time. On the other hand, the reverse is true in an industrial environment.

Zinc owes its high degree of resistance to atmospheric corrosion to the formation of insoluble basic carbonate films. Environmental conditions that interfere with the formation of such films may attack zinc quite rapidly. The most important factors that control the rate at which zinc corrodes in atmospheric exposures are:

- The duration and frequency of moisture contact
- The rate at which the surface dries
- The extent of industrial pollution of the atmosphere

The latter is the most important because the formation of basic corrosive films is prevented when the zinc is attacked by acidic moisture. The effect of industrial pollutants is illustrated by considering that in highly industrial environments a 2-oz/ft^2 (610-g/m^2) zinc coating will begin to exhibit rusting after 4 years and may be 80% rusted in 10 years. A similar coating would not be expected to display rusting after 30 to 40 years of exposure in rural atmospheres and after 15 to 25 years in marine environments.

In dry air, zinc is slowly attacked by atmospheric oxygen. A thin, dense layer of oxide is formed on the surface of the zinc, and a porous outer layer then forms on top of it. Although the outer layer breaks away occasionally, the thin under layer remains and protects the metal by restricting its interaction with the oxygen. Under these conditions, which occur in some inland tropical climates, the zinc oxidizes very slowly.

The rate of drying is also an important factor because of thin moisture film with higher oxygen concentration promotes corrosion. For normal exposure conditions, the films dry quite rapidly, and only in sheltered areas are drying times slow enough to accelerate the attack of the zinc significantly.

In coastal districts and industrial areas, the air is contaminated with water containing considerable amounts of dissolved salts. Sodium chloride (NaCl) is of course the main salt present in marine atmospheres, and oxides of sulfur are the most important pollutants in industrial and urban atmospheres. The oxides of sulfur dissolve in water to form sulfuric acid (H_2SO_4), which in turn reacts with the zinc hydroxide or zinc carbonate ($ZnCO_3$) formed on the surface to produce zinc sulfate ($ZnSO_4$). Because this salt is very soluble, it is easily removed by rainwater, and this leaves the zinc surface relatively unprotected. This solubility of the zinc corrosion products is one of the most important factors affecting the rate of corrosion of zinc in industrial atmospheres, and it primarily accounts for the fact that this rate may be as much as four or five times greater than that in rural or marine atmospheres, depending on the amount of sulfur present.

If a fresh zinc surface is allowed to stand with large drops of dew on it, as may easily happen if it is stored in a closed space in which the temperature varies periodically, it will be attacked by the oxygen dissolved in the drops of water. These drops of water conduct electricity slightly, and because the oxygen concentration is greater at the outer edges of the drops than at their centers, some electrochemical action results. Therefore, bulky deposits of porous zinc oxide (ZnO) or $Zn(OH)_2$ form on the surface instead of forming a protective layer all over it. This oxide quickly takes up carbon dioxide (CO_2) to form a basic carbonate, commonly known as wet-storage stain. This may form on any new zinc surface unless care is taken to store the metal in a dry airy place until the protective layer has formed over the entire surface. The formation of wet-storage stain may also be prevented by a simple chromate treatment.

Influence of Atmospheric Variables. Atmospheric corrosion has been defined to include corrosion by air temperatures between −18 and 70 °C (0 and 160 °F) in the open and in enclosed spaces of all kinds. Deterioration in the atmosphere is sometimes called weathering. This definition encompasses a great variety of environments of differing corrosivities. The factors that determine the corrosivity of an atmosphere include industrial pollution, marine pollution, humidity, temperature (especially the spread between daily highs and lows that influences condensation and evaporation of moisture), and rainfall. The atmosphere, as far as corrosion is concerned, is not a simple invariant environment. The influence of these factors on the corrosion of zinc is related to their effect on the initiation and growth of protective films.

Relative Humidity and Rainfall. In relatively dry air, the initial film formed on zinc surfaces is ZnO from the reaction of the zinc with atmospheric oxygen. This will converted to a hydroxide in the presence of moisture. These films have a relatively minor protective effect. The $Zn(OH)_2$ reacts further with CO_2 in the atmosphere, which forms a basic $ZnCO_3$. This film is very protective and is mainly responsible for the excellent resistance of zinc to ordinary atmospheres.

The significance of atmospheric humidity in the corrosion of zinc is related to the conditions that may cause condensation of moisture on the metal surface and to the frequency and duration of the moisture contact. If the air temperature drops below the dew point, moisture will be deposited. Similarly, lowering the temperature of a metal surface below the air temperature in a humid atmosphere will cause moisture to condense on the metal. If the water evaporates quickly, corrosion is usually not severe, and a protective film is formed on the surface. On the other hand, water that remains in contact with zinc at high humidities, and particularly under poorly ventilated conditions, may cause severe corrosion.

Rainfall is not considered to be a source of serious corrosion unless it remains in contact with the zinc for some time, particularly if access to air is limited. The weight losses sometimes observed after a heavy rainfall indicate the washing away of soluble corrosion products that formed before the rainfall.

In some short-term tests, zinc kept under a roof, but otherwise exposed to the atmosphere, corroded at about the same rate as completely exposed zinc. Sulfur dioxide (SO_2), not rain, is the significant factor in the corrosive attack. In long-term tests, however, the specimens protected from falling rain corroded at a rate considerably lower than that for completely exposed specimens. This is attributed to the formation of a

$ZnSO_4$ film on the samples under the roof that is not washed away by the rain. The surface is more acid and absorbs less SO_2 from the air. The higher corrosion rate in the open is not attributed directly to rainfall, but is attributed indirectly to the washing away of the protective film by the rain.

Results of tests on the effect of atmospheric pollution and rainfall on the corrosion of zinc proved that the pH of the rainwater and the total solids contents of the air have some significance. In highly industrial localities, the rainwater is contaminated by acidic sulfur compounds and becomes acidic enough to interfere with the formation of a protective film. This pH value is very significant because it interferes with the zinc formation of protective coatings of carbonates, sulfates, or oxides.

In acid rain environments, such coatings are never stabilized, because they are in a constant flux of dissolution. The United States and Canadian governments, as well as the Electric Power Research Institute, began investigations in the early 1980s on the acid rain corrosion of zinc and galvanized steel. These studies will provide detailed information on the long-term effects of acid rain on these metals.

Industrial and Marine Pollutants. In industrial or marine locations, condensed dew is likely to be contaminated with impurities that are corrosive to zinc. In such circumstances, the corrosivity of the contaminant may be more important than the degree of moisture condensation. Sulfur dioxide is one of the most harmful pollutants in the atmosphere, and it plays a major part in the corrosion of steel and zinc. Exposure tests showed that the correlation between sulfur pollution and corrosion is high for copper-bearing steel and for zinc, and these tests demonstrated that the SO_2 concentration in the air is the determining factor for the intensity of the corrosion of these metals.

Another series of tests found that even at test sites situated far from industrial towns the corrosion products contained a strong sulfate component derived from atmospheric sulfur compounds. This indicates that the effects of this type of pollution are far reaching.

Zinc Coatings. A zinc-coated surface is much less likely to suffer pitting attack than unprotected steel. In one series of tests, the depth of pits on unprotected steel was found to be up to six times the average loss of metal, whereas for zinc-coated steel the ratio was only two or three.

The behavior of zinc coatings of different thicknesses and applied by different methods was examined in tests under actual outdoor service conditions. Results showed that for a particular exposure condition the life of a zinc coating is approximately proportional to the weight of zinc and is independent of the method by which it is applied.

This is a very important result that should always be kept in mind when protective coatings are specified for a particular service application. If a steel structure or component is expected to have a long service life, it is always more economical to apply a sufficient heavy zinc coating at the start than to renew the coating later on because the initial zinc coating was of inadequate weight. The amount of surface preparation required is nearly always less with the new structure than with an old one and is the same whether a thick or thin coating is to be applied. On the other hand, there is no point in applying a heavy zinc coating to an article that will be discarded for other reasons after a short period of service under mildly corrosive conditions.

Zinc Die Castings. The corrosion behavior of zinc die castings in various natural atmospheres was investigated in a program extending over a 20-year period. Because mechanical properties have an important effect on the practical applications of die castings, changes in these properties were taken as a measure of corrosion damage rather than weight loss. Specimens of alloys AG41A (1% Cu) and AG40A (copper free) were exposed at several locations, and their mechanical properties were determined after 5, 10, and 20 years of exposure.

Round specimens measuring 6.4 mm (1/4 in.) in diameter were used for tensile tests, and 6.4 mm (1/4 in.) square bars were used as impact specimens. The percentage changes from the original values are included. As in all previous tests on zinc sheet, the industrial atmospheres appeared to be the most harmful. The differences between the rural and the mild indoor atmospheres were relatively minor.

A rather large decrease in the impact strength of both alloys occurred in the interval between the 10- and 20-year exposures in the industrial atmospheres. This also occurred for alloy AC41A exposed to the indoor atmospheres. Such decreases in mechanical properties are probably caused by intergranular attack can reduce cross-sectional areas and create stress-raising notches, but it does not reduce the overall specimen dimensions significantly.

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
1100-H14	A91100	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.07 mm (2.6 mils). Average depth of attack 0.029 mm (1.1 mils). Loss of tensile strength 0%	127
1135-H14	A91135	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.013)	Maximum depth of attack 0.08 mm (3.3 mils). Average depth of attack 0.037 mm (1.5 mils). Loss of tensile strength 0.4%	127
1188-H14	A91188	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.010)	Maximum depth of attack 0.121 mm (4.8 mils). Average depth of attack 0.046 mm (1.8 mils). Loss of tensile strength 0%	127

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
1199-H18	A91199	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0002 (0.008)	Maximum depth of attack 0.096 mm (3.8 mils). Average depth of attack 0.057 mm (2.2 mils). Loss of tensile strength 3.9%	127
Alclad 2014-T6	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.014)	Maximum depth of attack 0.043 mm (1.7 mils). Average depth of attack 0.028 mm (1.1 mils). Loss of tensile strength 0%	127
Alclad 2024-T3	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.010)	Maximum depth of attack 0.046 mm (1.8 mils). Average depth of attack 0.027 mm (1.1 mils). Loss of tensile strength 0%	127
Alclad 3003-H14	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.128 mm (5.0 mils). Average depth of attack 0.117 mm (4.68 mils). Loss of tensile strength 0%	127
Alclad 5155-H34	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.053 mm (2.1 mils). Average depth of attack 0.035 mm (1.4 mils). Loss of tensile strength 0%	127
Alclad 6061-T6	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.014)	Maximum depth of attack 0.098 mm (3.9 mils). Average depth of attack 0.025 mm (1.0 mils). Loss of tensile strength 0.7%	127
Alclad 7075-T6	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0005 (0.020)	Maximum depth of attack 0.053 mm (2.1 mils). Average depth of attack 0.041 mm (1.6 mils). Loss of tensile strength 0.1%	127
Alclad 7079-T6	...	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.013)	Maximum depth of attack 0.072 mm (2.8 mils). Average depth of attack 0.036 mm (1.4 mils). Loss of tensile strength 0%	127
2014-T6	A92014	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0006 (0.025)	Maximum depth of attack 0.077 mm (3.0 mils). Average depth of attack 0.050 mm (2.0 mils). Loss of tensile strength 1.7%	127
2024-T3	A92024	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0010 (0.040)	Maximum depth of attack 0.076 mm (3.0 mils). Average depth of attack 0.067 mm (2.6 mils). Loss of tensile strength 2.0%	127
2024-T3	A92024	...	Industrial; at Madison, IL, 1.5% change in tensile strength	...	...	...	0.002 (0.08)	...	14
2024-T3	A92024	...	Marine; at Kure Beach, NC, 2.5% change in tensile strength	...	...	...	0.002 (0.06)	...	14
2024-T3	A92024	...	Rural; near Midland, MI, 0.4% change in tensile strength	...	...	...	0.0001 (0.005)	...	14
2024-T81	A92024	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0007 (0.029)	Maximum depth of attack 0.097 mm (3.8 mils). Average depth of attack 0.076 mm (3.0 mils). Loss of tensile strength 6.0%	127
2024-T86	A92024	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0008 (0.032)	Maximum depth of attack 0.077 mm (3.0 mils). Average depth of attack 0.058 mm (2.3 mils). Loss of tensile strength 6.2%	127

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
5005-H34	A95005	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.015)	Maximum depth of attack 0.076 mm (3.0 mils). Average depth of attack 0.027 mm (1.1 mils). Loss of tensile strength 0.9%	127
5050-H34	A95050	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.107 mm (4.2 mils). Average depth of attack 0.058 mm (2.3 mils). Loss of tensile strength 0.5%	127
5052-H34	A95052	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.014)	Maximum depth of attack 0.062 mm (2.4 mils). Average depth of attack 0.043 mm (1.7 mils). Loss of tensile strength 0.8%	127
5083-H34	A95083	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.015)	Maximum depth of attack 0.088 mm (3.5 mils). Average depth of attack 0.056 mm (2.2 mils). Loss of tensile strength2.2%	127
5083-O	A95083	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0005 (0.019)	Maximum depth of attack 0.102 mm (4.0 mils). Average depth of attack 0.052 mm (2.0 mils). Loss of tensile strength 1.8%	127
5086-H34	A95086	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.017)	Maximum depth of attack 0.105 mm (4.1 mils). Average depth of attack 0.076 mm (3.0 mils). Loss of tensile strength 1.9%	127
5154-H34	A95154	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.013)	Maximum depth of attack 0.091 mm (3.6 mils). Average depth of attack 0.065 mm (2.6 mils). Loss of tensile strength 0.9%	127
5357-H34	A95357	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.012)	Maximum depth of attack 0.138 mm (5.4 mils). Average depth of attack 0.102 mm (4.0 mils). Loss of tensile strength 0.4%	127
5454-H34	A95454	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.105 mm (4.1 mils). Average depth of attack 0.030 mm (1.2 mils). Loss of tensile strength 0.5%	127
5454-O	A95454	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.014)	Maximum depth of attack 0.095 mm (3.7 mils). Average depth of attack 0.041 mm (1.6 mils). Loss of tensile strength 1.5%	127
5456-O	A95456	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.015)	Maximum depth of attack 0.104 mm (4.1 mils). Average depth of attack 0.037 mm (1.5 mils). Loss of tensile strength 0.4%	127
6061-T4	A96061	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.015)	Maximum depth of attack 0.57 mm (2.2 mils). Average depth of attack 0.038 mm (1.5 mils). Loss of tensile strength 0.4%	127
3003-H14	A93003	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.012)	Maximum depth of attack 0.086 mm (3.4 mils). Average depth of attack 0.052 mm (2.0 mils). Loss of tensile strength 1.1%	127

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
3004-H34	A93004	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0004 (0.016)	Maximum depth of attack 0.119 mm (4.7 mils). Average depth of attack 0.044 mm (1.7 mils). Loss of tensile strength 1.1%	127
4043-H14	A94034	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0003 (0.013)	Maximum depth of attack 0.105 mm (4.1 mils). Average depth of attack 0.034 mm (1.3 mils). Loss of tensile strength 2.8%	127
7075-T6	A97075	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0007 (0.027)	Maximum depth of attack 0.098 mm (3.9 mils). Average depth of attack 0.042 mm (1.7 mils). Loss of tensile strength 0.7%	127
7079-T6	A97079	...	Average values for Point Judith, RI (marine) and New Kensington, PA (industrial)	...	...	7 yr	0.0006 (0.025)	Maximum depth of attack 0.065 mm (2.6 mils). Average depth of attack 0.037 mm (1.5 mils). Loss of tensile strength 0.5%	127
Carbon and alloy steels									
Carbon steel	G10100	...	Marine steady state corrosion rates	...	...	.25-4 yr	.055 (2.20)	...	195
Carbon steel	G10100	...	Rural steady state corrosion rates	...	...	.25-4 yr	.026 (1.04)	...	195
Carbon steel	G10100	...	Rural-industrial steady state corrosion rates	...	...	.25-4 yr	.027 (1.08)	...	195
Carbon steel	G10100	...	Rural-industrial steady state corrosion rates	...	...	.25-4 yr	.028 (1.12)	...	195
Carbon steel	G10100	...	Urban steady state corrosion rates	...	...	.25-4 yr	.024 (0.96)	...	195
Carbon steel	G10100	...	Urban steady state corrosion rates	...	...	.25-4 yr	.024 (0.96)	...	195
Carbon steel	G10100	...	Urban steady state corrosion rates	...	...	.25-4 yr	.029 (1.16)	...	195
Carbon steel	G10100	...	Urban-industrial steady state corrosion rates	...	...	.25-4 yr	.036 (1.44)	...	195
Carbon steel	G10100	...	Urban-industrial steady state corrosion rates	...	...	.25-4 yr	.030 (1.2)	...	195
Carbon steel	G10100	...	Urban-industrial steady state corrosion rates	...	...	.25-4 yr	.037 (1.5)	...	195
Carbon steel	G10100	...	Urban-industrial steady state corrosion rates	...	...	.25-4 yr	.033 (1.30)	...	195
A242, type 1	K11510	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.005 (0.19)	...	125
A242, type 1	K11510	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.003 (0.10)	...	125
A242, type 1	K11510	...	Industrial (Newark, NJ)	...	...	15.5 yr	0.001 (0.06)	...	125
A242, type 1	K11510	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.015 (0.60)	...	125
A242, type 1	K11510	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.009 (0.37)	...	125
A242, type 1	K11510	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.006 (0.26)	...	125
A242, type 1	K11510	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.004 (0.17)	...	125
A242, type 1	K11510	...	Rural (Potter County, PA)	...	...	2.5 yr	0.004 (0.16)	...	125
A242, type 1	K11510	...	Rural (Potter County, PA)	...	...	3.5 yr	0.004 (0.16)	...	125
A242, type 1	K11510	...	Rural (Potter County, PA)	...	...	7.5 yr	0.002 (0.09)	...	125
A242, type 1	K11510	...	Rural (Potter County, PA)	...	...	15.5 yr	0.001 (0.05)	...	125
A242, type 1	K11510	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.009 (0.37)	...	125

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
A242, type 1	K11510	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.004 (0.17)	...	125
A242, type 1	K11510	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.002 (0.09)	...	125
A242, type 1	K11510	...	Semi-industrial (Monroeville, PA)	...	...	15.5 yr	0.001 (0.05)	...	125
A242, type 1	K11510	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.008 (0.33)	...	125
A242, type 1	K11510	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.002 (0.19)	...	125
A242, type 1	K11510	...	Semi-industrial (South Bend, PA)	...	...	15.5 yr	0.002 (0.07)	...	125
A242, type 1	K11510	...	Semi-industrial South Bend, PA)	...	...	7.5 yr	0.003 (0.12)	...	125
A242, type 1	K11510	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	0.5 yr	0.055 (2.20)	...	125
A242, type 1	K11510	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	2.0 yr	0.021 (0.83)	...	125
A242, typel	K11510	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	5.0 yr	0.049 (1.94)	...	125
A514, type B	K11630	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.003 (0.11)	...	125
A514, type B	K11630	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.005 (0.20)	...	125
A514, type B	K11630	...	Industrial (Newark, NJ)	...	...	15.5 yr	0.002 (0.06)	...	125
A514, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.018 (0.70)	...	125
A514, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.010 (0.40)	...	125
A514, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.007 (0.27)	...	125
A514, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.005 (0.19)	...	125
A514, type B	K11630	...	Rural (Potter County, PA)	...	...	3.5 yr	0.004 (0.17)	...	125
A514, type B	K11630	...	Rural (Potter County, PA)	...	...	7.5 yr	0.003 (0.10)	...	125
A514, type B	K11630	...	Rural (Potter County, PA)	...	...	15.5 yr	0.002 (0.06)	...	125
A514, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.010 (0.40)	...	125
A514, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.005 (0.20)	...	125
A514, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.003 (0.11)	...	125
A514, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	15.5 yr	0.002 (0.06)	...	125
A514, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.008 (0.33)	...	125
A514, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.005 (0.21)	...	125
A514, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	7.5 yr	0.003 (0.13)	...	125
A514, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	15.5 yr	0.002 (0.08)	...	125
A514, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	0.5 yr	0.028 (0.11)	...	125
A514, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	3.5 yr	0.014 (0.55)	...	125
A514, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	5.0 yr	0.013 (0.55)	...	125
A514, type F	K11576	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.040 (1.60)	...	125
A514, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.025 (1.0)	...	125

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
A514, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.014 (0.56)	...	125
A514, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.008 (0.31)	...	125
A514, type F	K11576	...	Rural (Potter County, PA)	...	...	3.5 yr	0.006 (0.26)	...	125
A514, type F	K11576	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.013 (0.53)	...	125
A514, type F	K11576	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.009 (0.34)	...	125
A514, type F	K11576	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.013 (0.50)	...	125
A514, type F	K11576	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.009 (0.34)	...	125
A514, type F	K11576	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	0.5 yr	0.018 (0.70)	...	125
A514, type F	K11576	...	Severe marine (Kure beach, NC, 20 m or 80 ft from ocean)	...	...	2.0 yr	0.013 (0.53)	...	125
A514, type F	K11576	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	3.5 yr	0.014 (0.55)	...	125
A517, type B	K11630	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.005 (0.20)	...	125
A517, type B	K11630	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.003 (0.11)	...	125
A517, type B	K11630	...	Industrial (Newark, NJ)	...	...	15.5 yr	0.002 (0.06)	...	125
A517, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.018 (0.70)	...	125
A517, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.010 (0.40)	...	125
A517, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.007 (0.27)	...	125
A517, type B	K11630	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.005 (0.19)	...	125
A517, type B	K11630	...	Rural (Potter County, PA)	...	...	3.5 yr	0.004 (0.17)	...	125
A517, type B	K11630	...	Rural (Potter County, PA)	...	...	7.5 yr	0.003 (0.10)	...	125
A517, type B	K11630	...	Rural (Potter County, PA)	...	...	15.5 yr	0.002 (0.06)	...	125
A517, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.010 (0.40)	...	125
A517, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.005 (0.20)	...	125
A517, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.003 (0.11)	...	125
A517, type B	K11630	...	Semi-industrial (Monroeville, PA)	...	...	15.5 yr	0.002 (0.06)	...	125
A517, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.008 (0.33)	...	125
A517, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.005 (0.21)	...	125
A517, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	7.5 yr	0.003 (0.13)	...	125
A517, type B	K11630	...	Semi-industrial (South Bend, PA)	...	...	15.5 yr	0.002 (0.08)	...	125
A517, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	0.5 yr	0.028 (0.11)	...	125
A517, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	3.5 yr	0.014 (0.55)	...	125
A517, type B	K11630	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	5.0 yr	0.013 (0.55)	...	125
A517, type F	K11576	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.040 (1.60)	...	125
A517, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.025 (1.0)	...	125

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Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
A517, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.014 (0.56)	...	125
A517, type F	K11576	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.008 (0.31)	...	125
A517, type F	K11576	...	Rural (Potter County, PA)	...	...	3.5 yr	0.006 (0.26)	...	125
A517, type F	K11576	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.013 (0.53)	...	125
A517, type F	K11576	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.009 (0.34)	...	125
A517, type F	K11576	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.013 (0.50)	...	125
A517, type F	K11576	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.009 (0.34)	...	125
A517, type F	K11576	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	0.5 yr	0.018 (0.70)	...	125
A517, type F	K11576	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	2.0 yr	0.013 (0.53)	...	125
A517, type F	K11576	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	3.5 yr	0.014 (0.55)	...	125
A588, grade A	K11430	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.006 (0.26)	...	125
A588, grade A	K11430	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.004 (0.14)	...	125
A588, grade A	K11430	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.020 (0.80)	...	125
A588, grade A	K11430	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.014 (0.57)	...	125
A588, grade A	K11430	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.009 (0.36)	...	125
A588, grade A	K11430	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.006 (0.25)	...	125
A588, grade A	K11430	...	Rural (Potter County, PA)	...	...	2.5 yr	0.006 (0.24)	...	125
A588, grade A	K11430	...	Rural (Potter County, PA)	...	...	3.5 yr	0.005 (0.20)	...	125
A588, grade A	K11430	...	Rural (Potter County, PA)	...	...	7.5 yr	0.003 (0.10)	...	125
A588, grade A	K11430	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.012 (0.47)	...	125
A588, grade A	K11430	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.008 (0.30)	...	125
A588, grade A	K11430	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.004 (0.16)	...	125
A588, grade A	K11430	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.011 (0.43)	...	125
A588, grade A	K11430	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.007 (0.27)	...	125
A588, grade A	K11430	...	Semi-industrial (South Bend, PA)	...	...	7.5 yr	0.005 (0.18)	...	125
A588, grade A	K11430	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	0.5 yr	0.095 (3.80)	...	125
A588, grade A	K11430	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	2.0 yr	0.076 (3.05)	...	125
A588, grade A	K11430	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	3.5 yr	0.100 (4.10)	...	125
A588, grade A	K11430	...	Severe marine (Kure Beach, NC, 20 m or 80 ft from ocean)	...	...	5.0 yr	0.095 (3.90)	...	125
Low Carbon Steel - 0.27%Cu	K12810	...	Rural; near Midland, MI, 7.5% change in tensile strength	...	...	...	0.015 (0.59)	...	14
Low Carbon Steel- 0.27%Cu	K12810	...	Industrial; at Madison, IL, 11.9% change in tensile strength	...	...	...	0.025 (1.00)	...	14
Low Carbon Steel- 0.27%Cu	K12810	...	Marine; at Kure Beach, NC, 75.4% change in tensile strength	...	...	...	0.150 (5.91)	...	14

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Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Structural copper steel	K12810	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.009 (0.37)	...	125
Structural copper steel	K12810	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.005 (0.21)	...	125
Structural copper steel	K12810	...	Industrial (Newark, NJ)	...	...	15.5 yr	0.003 (0.13)	...	125
Structural copper steel	K12810	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.020 (0.80)	...	125
Structural copper steel	K12810	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.016 (0.63)	...	125
Structural copper steel	K12810	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.012 (0.47)	...	125
Structural copper steel	K12810	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.008 (0.30)	...	125
Structural copper steel	K12810	...	Rural (Potter County, PA)	...	...	2.5 yr	0.007 (0.26)	...	125
Structural copper steel	K12810	...	Rural (Potter County, PA)	...	...	3.5 yr	0.006 (0.24)	...	125
Structural copper steel	K12810	...	Rural (Potter County, PA)	...	...	7.5 yr	0.004 (0.16)	...	125
Structural copper steel	K12810	...	Rural (Potter County, PA)	...	...	15.5 yr	0.003 (0.12)	...	125
Structural copper steel	K12810	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.014 (0.56)	...	125
Structural copper steel	K12810	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.009 (0.36)	...	125
Structural copper steel	K12810	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.005 (0.21)	...	125
Structural copper steel	K12810	...	Semi-industrial (Monroeville, PA)	...	...	15.5 yr	0.004 (0.15)	...	125
Structural copper steel	K12810	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.012 (0.46)	...	125
Structural copper steel	K12810	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.008 (0.31)	...	125
Structural copper steel	K12810	...	Semi-industrial (South Bend, PA)	...	...	7.5 yr	0.005 (0.21)	...	125
Structural copper steel	K12810	...	Semi-industrial (South Bend, PA)	...	...	15.5 yr	0.004 (0.15)	...	125
Structural copper steel	K12810	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	0.5 yr	0.11 (4.30)	...	125
Structural copper steel	K12810	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	2.0 yr	0.12 (4.8)	...	125
Structural copper steel	K12810	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	3.5 yr	0.14 (5.4)	...	125
Structural copper steel	K12810	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	5.0 yr	...	Specimen completely corroded away	125
1050 steel	G10500	...	65% RH. lab test	...	20	7 d	0.031 (1.24)	...	200
1050 steel	G10500	...	65% RH. lab test + coal fly ash	...	20	7 d	0.031 (1.24)	...	200
1050 steel	G10500	...	65% RH. lab test + oil fly ash	...	20	7 d	0.088 (3.50)	...	200
1050 steel	G10500	...	80% RH. lab test	...	20	7 d	0.038 (1.50)	...	200
1050 steel	G10500	...	80% RH. lab test + coal fly ash	...	20	7 d	0.062 (2.51)	...	200
1050 steel	G10500	...	80% RH. lab test + oil fly ash	...	20	7 d	0.23 (9.5)	...	200
1050 steel	G10500	...	90% RH. lab test	...	20	7 d	0.038 (1.50)	...	200
1050 steel	G10500	...	90% RH. lab test + coal fly ash	...	20	7 d	0.15 (6.02)	...	200
1050 steel	G10500	...	90% RH. lab test + oil fly ash	...	20	7 d	0.35 (14.0)	...	200
Structural carbon steel	G10100	...	Industrial (Newark, NJ)	...	...	3.5 yr	0.012 (0.47)	...	125

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Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Structural carbon steel	G10100	...	Industrial (Newark, NJ)	...	...	7.5 yr	0.007 (0.27)	...	125
Structural carbon steel	G10100	...	Industrial (Newark, NJ)	...	...	15.5 yr	0.004 (0.17)	...	125
Structural carbon steel	G10100	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	0.5 yr	0.023 (0.90)	...	125
Structural carbon steel	G10100	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	1.5 yr	0.019 (0.77)	...	125
Structural carbon steel	G10100	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	3.5 yr	0.018 (0.70)	...	125
Structural carbon steel	G10100	...	Moderate marine (Kure Beach, NC, 250 m or 800 ft from ocean)	...	...	7.5 yr	0.009 (0.37)	...	125
Structural carbon steel	G10100	...	Rural (Potter County, PA)	...	...	3.5 yr	0.007 (0.29)	...	125
Structural carbon steel	G10100	...	Rural (Potter County, PA)	...	...	7.5 yr	0.005 (0.20)	...	125
Structural carbon steel	G10100	...	Rural (Potter County, PA)	...	...	15.5 yr	0.004 (0.15)	...	125
Structural carbon steel	G10100	...	Semi-industrial (Monroeville, PA)	...	...	1.5 yr	0.018 (0.73)	...	125
Structural carbon steel	G10100	...	Semi-industrial (Monroeville, PA)	...	...	3.5 yr	0.013 (0.53)	...	125
Structural carbon steel	G10100	...	Semi-industrial (Monroeville, PA)	...	...	7.5 yr	0.009 (0.34)	...	125
Structural carbon steel	G10100	...	Semi-industrial (Monroeville, PA)	...	...	15.5 yr	0.006 (0.24)	...	125
Structural carbon steel	G10100	...	Semi-industrial (South Bend, PA)	...	...	1.5 yr	0.015 (0.60)	...	125
Structural carbon steel	G10100	...	Semi-industrial (South Bend, PA)	...	...	3.5 yr	0.010 (0.41)	...	125
Structural carbon steel	G10100	...	Semi-industrial (South Bend, PA)	...	...	7.5 yr	0.008 (0.31)	...	125
Structural carbon steel	G10100	...	Semi-industrial (South Bend, PA)	...	...	15.5 yr	0.006 (0.23)	...	125
Structural carbon steel	G10100	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	0.5 yr	0.180 (7.20)	...	125
Structural carbon steel	G10100	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	2.0 yr	0.23 (9.0)	...	125
Structural carbon steel	G10100	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	3.5 yr	0.20 (8.1)	...	125
Structural carbon steel	G10100	...	Severe marine (Kure Beach, NC, 25 m or 80 ft from ocean)	...	...	5.0 yr	...	Specimen corroded completely away	125
Copper and alloys									
7% Aluminum bronze	C61000	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0005 (0.002)	...	25
7% Aluminum bronze	C61000	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0002 (0.006)	...	25
7% Aluminum bronze	C61000	...	Industrial marine (New York, NY)	...	...	20 yr	0.0016 (0.063)	...	25
7% Aluminum bronze	C61000	...	Industrial (Altoona, PA)	...	...	20 yr	0.0016 (0.064)	...	25
7% Aluminum bronze	C61000	...	Northern rural (State College, PA)	...	...	20 yr	0.0003 (0.010)	...	25
7% Aluminum bronze	C61000	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0001 (0.004)	...	25
Aluminum bronze	...	...	Industrial	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Marine	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Rural	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Brass	...	...	Industrial	...	...	...	Resistant	...	93
Brass	...	...	Marine	...	...	...	Resistant	...	93
Brass	...	...	Rural	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Rural	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.004)	...	25
Cartridge brass	C26000	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0002 (0.006)	...	25
Cartridge brass	C26000	...	Industrial marine (New York, NY)	...	...	20 yr	0.0024 (0.095)	...	25
Cartridge brass	C26000	...	Industrial	...	...	...	Good	...	93
Cartridge brass	C26000	...	Industrial (Altoona, PA)	...	...	20 yr	0.0031 (0.120)	...	25
Cartridge brass	C26000	...	Marine	...	...	...	Good	...	93
Cartridge brass	C26000	...	Northern rural (State College, PA)	...	...	20 yr	0.0005 (0.018)	...	25
Cartridge brass	C26000	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0002 (0.008)	...	25
Commercial bronze	C22000	...	Industrial	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Marine	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Rural	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Industrial	...	...	...	Good	...	93
Muntz metal	C28000	...	Marine	...	...	...	Good	...	93
Muntz metal	C28000	...	Rural	...	...	...	Resistant	...	93
Red brass	C23000	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.004)	...	25
Red brass	C23000	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0003 (0.013)	...	25
Red brass	C23000	...	Industrial marine (New York, NY)	...	...	20 yr	0.0019 (0.074)	...	25
Red brass	C23000	...	Industrial	...	...	...	Resistant	...	93
Red brass	C23000	...	Industrial (Altoona, PA)	...	...	20 yr	0.0019 (0.074)	...	25
Red brass	C23000	...	Marine	...	...	...	Resistant	...	93
Red brass	C23000	...	Northern rural (State College, PA)	...	...	20 yr	0.0005 (0.018)	...	25
Red brass	C23000	...	Rural	...	...	...	Resistant	...	93
Red brass	C23000	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0006 (0.022)	...	25
DHP copper	C12000	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.003)	...	25
DHP copper	C12000	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0014 (0.056)	...	25
DHP copper	C12000	...	Industrial marine (New York, NY)	...	...	20 yr	0.0012 (0.048)	...	25
DHP copper	C12000	...	Industrial (Altoona, PA)	...	...	20 yr	0.0013 (0.052)	...	25
DHP copper	C12000	...	Northern rural (State College, PA)	...	...	20 yr	0.0004 (0.014)	...	25
DHP copper	C12000	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0005 (0.020)	...	25
Electrolytic copper	C11000	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.005)	...	25
Electrolytic copper	C11000	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0013 (0.050)	...	25
Electrolytic copper	C11000	...	Industrial marine (New York, NY)	...	...	20 yr	0.0014 (0.054)	...	25
Electrolytic copper	C11000	...	Industrial	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Industrial (Altoona, PA)	...	...	20 yr	0.0014 (0.055)	...	25
Electrolytic copper	C11000	...	Marine	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Northern rural (State College, PA)	...	...	20 yr	0.0004 (0.017)	...	25
Electrolytic copper	C11000	...	Rural	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Electrolytic copper	C11000	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0006 (0.022)	...	25
Phosphor copper	C12200	...	Industrial	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Marine	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Rural	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Industrial	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Marine	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Rural	...	...	...	Resistant	...	93
70Cu-29Ni-1Sn	...	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.004)	...	25
70Cu-29Ni-1Sn	...	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0004 (0.014)	...	25
70Cu-29Ni-1Sn	...	...	Industrial marine (New York, NY)	...	...	20 yr	0.0021 (0.084)	...	25
70Cu-29Ni-1Sn	...	...	Industrial (Altoona, PA)	...	...	20 yr	0.0026 (0.104)	...	25
70Cu-29Ni-1Sn	...	...	Northern rural (State College, PA)	...	...	20 yr	0.0005 (0.019)	...	25
70Cu-29Ni-1Sn	...	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0003 (0.011)	...	25
90-10 cupronickel	C70600	...	Industrial	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Marine	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Rural	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Industrial	...	...	...	Good	...	93
Architectural bronze	C38500	...	Marine	...	...	...	Good	...	93
Architectural bronze	C38500	...	Rural	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Industrial	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Marine	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Rural	...	...	...	Resistant	...	93
Nickel-silver, 18% N	...	...	Marine	...	...	...	Resistant	...	93
Nickel-silver, 18% N	...	...	Rural	...	...	...	Resistant	...	93
Nickel-silver, 18% Ni	...	...	Industrial	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Industrial	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Marine	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Rural	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0023 (0.091)	...	25
Phosphor bronze, 8% Sn	C52100	...	Industrial marine (New York, NY)	...	...	20 yr	0.0025 (0.100)	...	25
Phosphor bronze, 8% Sn	C52100	...	Industrial	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Industrial (Altoona, PA)	...	...	20 yr	0.0022 (0.088)	...	25
Phosphor bronze, 8% Sn	C52100	...	Marine	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Northern rural (State College, PA)	...	...	20 yr	0.0003 (0.013)	...	25
Phosphor bronze, 8% Sn	C52100	...	Rural	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Tropical rural marine (Key West, FL)	...	...	20 yr	0.0007 (0.028)	...	25
Phosphor bronze, 8%Sn	C52100	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.005)	...	25

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Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silicon bronze, high	C65500	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0002 (0.006)	...	25
Silicon bronze, high	C65500	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0014 (0.054)	...	25
Silicon bronze, high	C65500	...	Industrial marine (New York, NY)	...	...	20 yr	0.0017 (0.068)	...	25
Silicon bronze, high	C65500	...	Industrial	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Industrial (Altoona, PA)	...	...	20 yr	0.0017 (0.065)	...	25
Silicon bronze, high	C65500	...	Marine	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Northern rural (State College, PA)	...	...	20 yr	0.0005 (0.020)	...	25
Silicon bronze, high	C65500	...	Rural	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Tropical rural marine (Key West, FL)	...	...	20 yr	()	...	25
Silicon bronze, low	C65100	...	Industrial	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Marine	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Rural	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Industrial	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Marine	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Rural	...	...	...	Resistant	...	93
Naval brass	C46400	...	Industrial	...	...	...	Good	...	93
Naval brass	C46400	...	Marine	...	...	...	Resistant	...	93
Naval brass	C46400	...	Rural	...	...	...	Resistant	...	93
Tin brass	C44200	...	Dry rural (Phoenix, AZ)	...	...	20 yr	0.0001 (0.004)	...	25
Tin brass	C44200	...	Humid marine (LaJolla, CA)	...	...	20 yr	0.0003 (0.013)	...	25
Tin brass	C44200	...	Industrial marine (New York, NY)	...	...	20 yr	0.0025 (0.099)	...	25
Tin brass	C44200	...	Industrial (Altoona, PA)	...	...	20 yr	0.0021 (0.084)	...	25
Tin brass	C44200	...	Northern rural (State College, PA)	...	...	20 yr	0.0005 (0.021)	...	25
Tin brass	C44200	...	Tropical rural marine (Key West, FL)	...	...	20 yr	...	...	25
Miscellaneous									
Lead, 99.95	L50045	...	Rural (Cardington, UK)	...	...	1 yr	0.0014 (0.056)	...	129
Lead, chemical	L51120	...	Industrial (Newark, NJ)	...	...	2 yr	0.0014 (0.056)	...	129
Lead, chemical	L51120	...	Tropical, inland (Miraflores, CZ)	...	...	8 yr	0.0007 (0.030)	...	129
Lead, chemical	L51120	...	Tropical, marine (Cristobal, CZ)	...	...	8 yr	0.0013 (0.053)	...	129
Lead, chemical	L51120	...	Seacoast (Key West, FL)	...	...	10 yr	0.0006 (0.023)	...	129
Lead, chemical	L51120	...	Seacoast (Sandy Hook, NJ)	...	...	20 yr	0.0005 (0.021)	...	129
Lead, 1 % Sb	...	...	Industrial (New York, NY)	...	...	20 yr	0.0003 (0.013)	...	129
Lead, 1 % Sb	...	...	Seacoast (LaJolla, CA)	...	...	20 yr	0.0006 (0.023)	...	129
Lead, 1 % Sb	...	...	Seacoast (Sandy Hook, NJ)	...	...	20 yr	0.0005 (0.020)	...	129
Lead, 1% Sb	...	...	Industrial (Altoona, PA)	...	...	10 yr	0.0006 (0.023)	...	129
Lead, 1% Sb	...	...	Rural (State College, PA)	...	...	20 yr	0.0003 (0.014)	...	129
Lead, 1% Sb	...	...	Seacoast (Key West, FL)	...	...	10 yr	0.0005 (0.022)	...	129
Lead, 1% Sb	...	...	Semi-arid (Phoenix, AZ)	...	...	20 yr	0.0003 (0.012)	...	129
Lead, 1.6% Sb	...	...	Urban (Birmingham, UK)	...	...	7 yr	0.0001 (0.004)	...	129
Lead, 6% Sb	L53110	...	East coast, marine (Kure Beach, NC) 80-ft site	...	...	2 yr	0.0010 (0.041)	...	129
Lead, 6% Sb	L53110	...	Industrial (Newark, NJ)	...	...	2 yr	0.0010 (0.042)	...	129
Lead, 6% Sb	L53110	...	Rural (State College, PA)	...	...	2 yr	0.0010 (0.039)	...	129
Lead, 6% Sb	L53110	...	West coast, marine (Point Reyes, CA)	...	...	2 yr	0.0006 (0.026)	...	129

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Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead, 99.95	L50045	...	Industrial (Wakefield, UK)	...	...	1 yr	0.0018 (0.074)	...	129
Lead, 99.95	L50045	...	Marine (Southport, UK)	...	...	1 yr	0.0017 (0.070)	...	129
Lead, 99.95	L50045	...	Suburban (Bourneville, UK)	...	...	1 yr	0.0019 (0.077)	...	129
Lead, 99.96	L50045	...	Urban (Birmingham, UK)	...	...	7 yr	0.0009 (0.037)	...	129
Lead, chemical	L51120	...	East coast, marine (Kure Beach, NC) 80-ft site	...	...	2 yr	0.0013 (0.052)	...	129
Lead, chemical	L51120	...	Industrial (Altoona, PA)	...	...	10 yr	0.0007 (0.029)	...	129
Lead, chemical	L51120	...	Industrial (New York, NY)	...	...	20 yr	0.0004 (0.015)	...	129
Lead, chemical	L51120	...	Rural (State College, PA)	...	...	20 yr	0.0003 (0.013)	...	129
Lead, chemical	L51120	...	Rural (State College, PA)	...	...	2 yr	0.0014 (0.055)	...	129
Lead, chemical	L51120	...	Seacoast (LaJolla, CA)	...	...	20 yr	0.0005 (0.021)	...	129
Lead, chemical	L51120	...	Semi-arid (Phoenix, AZ)	...	...	20 yr	0.0001 (0.004)	...	129
Lead, chemical	L51120	...	West coast, marine (Point Reyes, CA)	...	...	2 yr	0.0009 (0.036)	...	129
AZ31B	...	...	Industrial; at Madison, IL, 11.2% change in tensile strength	...	...	...	0.027 (1.09)	...	14
AZ31B	...	...	Marine; at Kure Beach NC, 7.4% change in tensile strength	...	...	...	0.018 (0.70)	...	14
AZ31B	...	...	Rural; near Midland, MI, 5.9% change in tensile strength	...	...	...	0.013 (0.53)	...	14
Tin	...	...	Marine (Florida)	...	...	10 yr	0.0023 (0.09)	...	128
Tin	..	...	Marine (New Jersey)	...	...	10 yr	0.0019 (0.075)	...	128
Tin	...	...	Heavy Industrial	...	...	20 yr	0.0017 (0.067)	...	128
Tin	...	...	Marine (California)	...	...	20 yr	0.0029 (0.11)	...	128
Tin	...	...	Marine heavy industrial	...	...	20 yr	0.0013 (0.051)	...	128
Tin	...	...	Rural	...	...	10 yr	0.0005 (0.019)	...	128
Tin	...	...	Semi-arid	...	...	20 yr	0.0004 (0.017)	...	128
Zinc	Z13001	...	65% RH. lab test	...	20	7 d	0.004 (0.15)	...	200
Zinc	Z13001	...	65% RH. lab test + coal fly ash	...	20	7 d	0.006 (0.25)	...	200
Zinc	Z13001	...	65% RH. lab test + oil fly ash	...	20	7 d	0.015 (0.60)	...	200
Zinc	Z13001	...	80% RH. lab test	...	20	7 d	0.004 (0.15)	...	200
Zinc	Z13001	...	80% RH. lab test + coal fly ash	...	20	7 d	0.006 (0.25)	...	200
Zinc	Z13001	...	80% RH. lab test + oil fly ash	...	20	7 d	0.019 (0.75)	...	200
Zinc	Z13001	...	90% RH. lab test	...	20	7 d	0.004 (0.15)	...	200
Zinc	Z13001	...	90% RH. lab test + coal fly ash	...	20	7 d	0.015 (0.60)	...	200
Zinc	Z13001	...	90% RH. lab test + oil fly ash	...	20	7 d	0.040 (1.60)	...	200
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH	...	22	420 h	0.19 (7.5)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 140 mg/cm^2 NaCl added	...	22	420 h	0.35 (14)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 140 mg/cm^2 NaCl added	...	22	420 h	0.53 (21)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 14 mg/cm^2 NaCl added	...	22	420 h	0.20 (7.9)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 14 mg/cm^2 NaCl added	...	22	420 h	0.06 (2.2)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 280 mg/cm_2 NaCl added	...	22	420 h	0.55 (22)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 280 mg/cm^2 NaCl added	...	22	420 h	0.65 (26)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 70 mg/cm^2 NaCl added	...	22	420 h	0.33 (13)	...	192
Zinc	Z13001	...	Lab test, 0.78 ppm SO_2, 95% RH. 70 mg/cm^2 NaCl added	...	22	420 h	0.33 (13)	...	192

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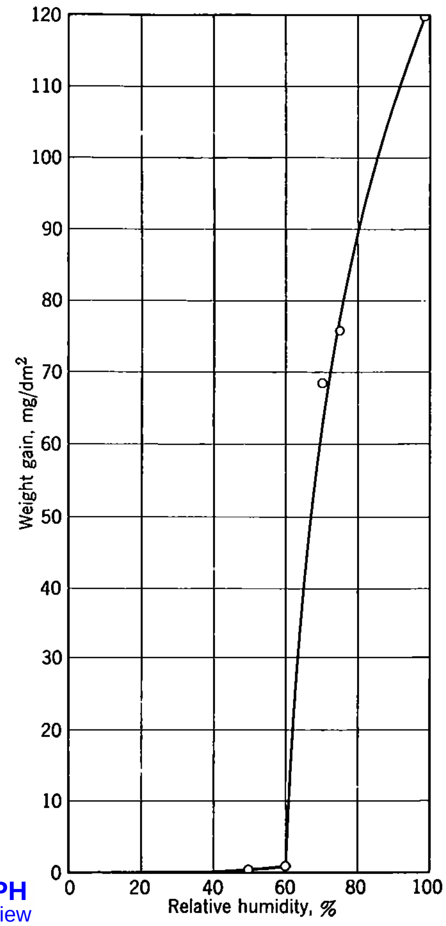
Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zinc	Z13001	...	Lab test, 0.78 pure air, 95% RH	...	22	420 h	.003 (0.1)	...	192
Stainless steels									
16-16-1	...	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0018 (.07)	255
16-16-1	...	1/2 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0020 (.08)	255
16-16-1	...	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
16-16-1	...	1/2 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
201	S20100	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0020 (.08)	255
201	S20100	1/4 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0025 (.10)	255
201	S20100	1/2 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0023 (.09)	255
201	S20100	3/4 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0023 (.09)	255
201	S20100	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
201	S20100	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
201	S20100	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .003 (.05)	255
201	S20100	1/4 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
201	S20100	1/2 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
201	S20100	3/4 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
201	S20100	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
201	S20100	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0018 (.07)	255
301	S30100	...	...	...	...	...	Resistant	...	253
301	S30100	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0020 (.08)	255
301	S30100	1/4 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0025 (.10)	255
301	S30100	1/2 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0030 (.12)	255
301	S30100	3/4 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
301	S30100	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
301	S30100	1/4 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
301	S30100	1/2 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
301	S30100	3/4 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
302	S30200	...	...	...	...	...	Resistant	...	253
302	S30200	No. 7	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0018 (.07)	255
302	S30200	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
302	S30200	1/4 CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
302	S30200	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
302	S30200	No. 4	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
302	S30200	No. 7	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
302	S30200	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
302	S30200	1/4 CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
302	S30200	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
302	S30200	No. 4	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
303	S30300	...	...	...	...	...	Good	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304	S30400	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0018 (.07)	255
304	S30400	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
304	S30400	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
304	S30400	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
304L	S30403	...	...	...	...	...	Resistant	...	253
304L	S30403	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0025 (.10)	255
304L	S30403	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255

(Continued)

Corrosion Behavior of Various Metals and Alloys in Atmospheric Environments (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316	S31600	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
316	S31600	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
316	S31600	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
316	S31600	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0005 (.02)	255
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316L	S31603	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
316L	S31603	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0008 (.03)	255
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
321	S32100	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
321	S32100	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0010 (.04)	255
347	S34700	...	...	...	...	...	Resistant	...	253
347	S34700	Soft 2B	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0015 (.06)	255
347	S34700	Soft 2B	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
329	S32900	...	...	...	...	...	Resistant	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253
430	S43000	Soft CR	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0028 (.11)	255
405	S40500	...	...	...	...	...	Good	...	253
409	S40900	...	...	...	...	...	Good	...	253
430	S43000	...	...	...	...	...	Good	...	253
430	S43000	Soft CR	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0013 (.05)	255
434	S43400	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Good	...	253
410	S41000	...	...	...	...	...	Good	...	253
410	S41000	Annealed No. 2	Marine atmosphere - 25 m lot	...	...	26 yr	...	Pitting .0030 (.12)	255
410	S41000	Annealed No. 2	Marine atmosphere - 250 m lot	...	...	26 yr	...	Pitting .0020 (.08)	255
416	S41600	...	...	...	...	...	Good	...	253
420	S42000	...	...	...	...	...	Good	...	253



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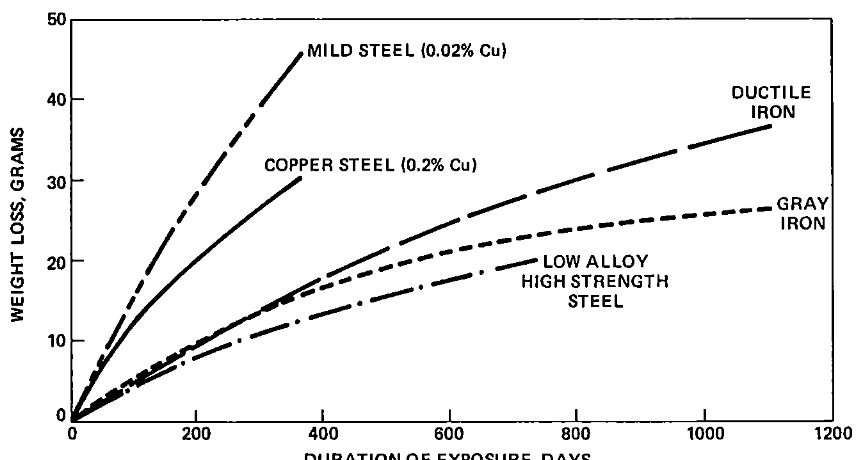
Iron. Corrosion of iron in air containing 0.01% SO_2 after 55 days of exposure, showing critical humidity. Source: H.H. Uhlig, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, John Wiley & Sons, New York, 1963, 147.



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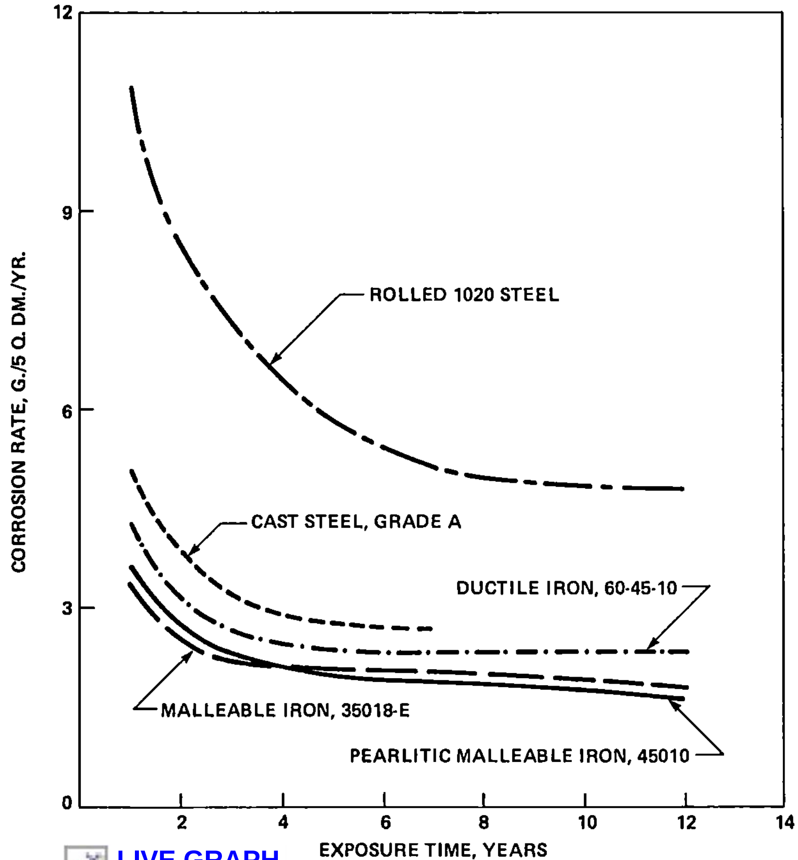
Steels and cast irons. Results of exposure of steels and cast irons to corrosion by atmosphere at Kure, NC, Beach 80 ft from the ocean. Source: C. McCaul and S. Goldspiel, "Atmospheric Corrosion of Malleable and Cast Irons and Steels," in *Atmospheric Corrosion*, W.H. Ailor, Ed., John Wiley & Sons, New York, 1982, 440.



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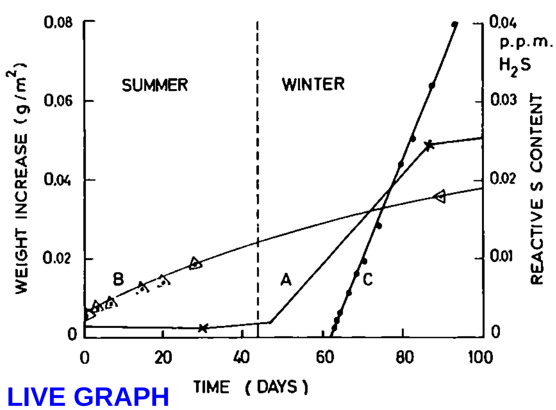
Steel and cast irons. Corrosion rates for ferrous metals exposed 12 years. Source: C. McCaul and S. Goldspiel, "Atmospheric Corrosion of Malleable and Cast Irons and Steels," in *Atmospheric Corrosion*, W.H. Ailor, Ed., John Wiley & Sons, New York, 1982, 439.



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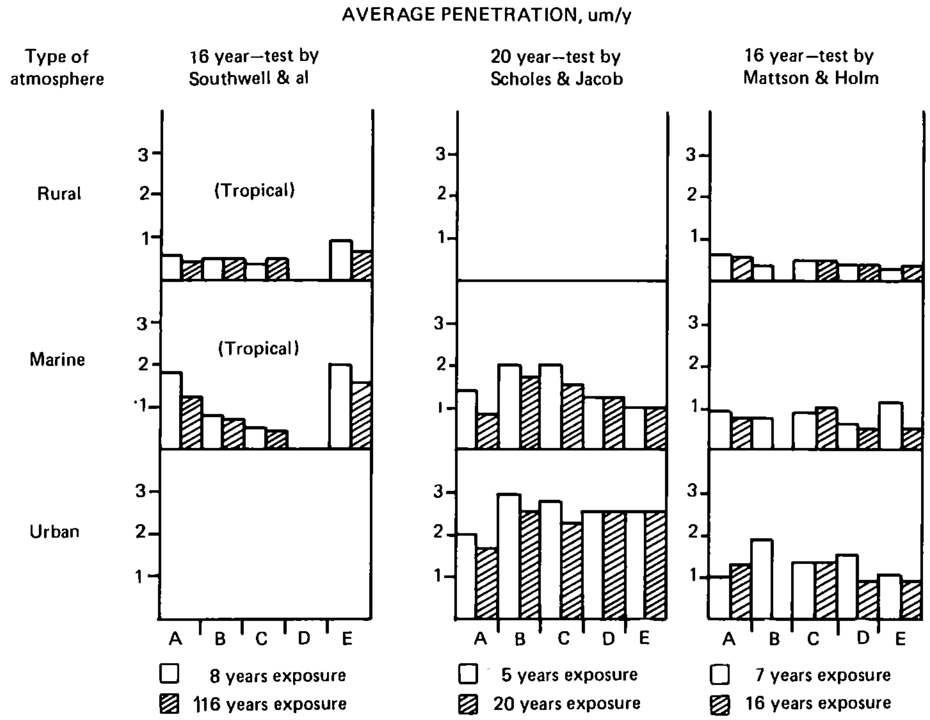
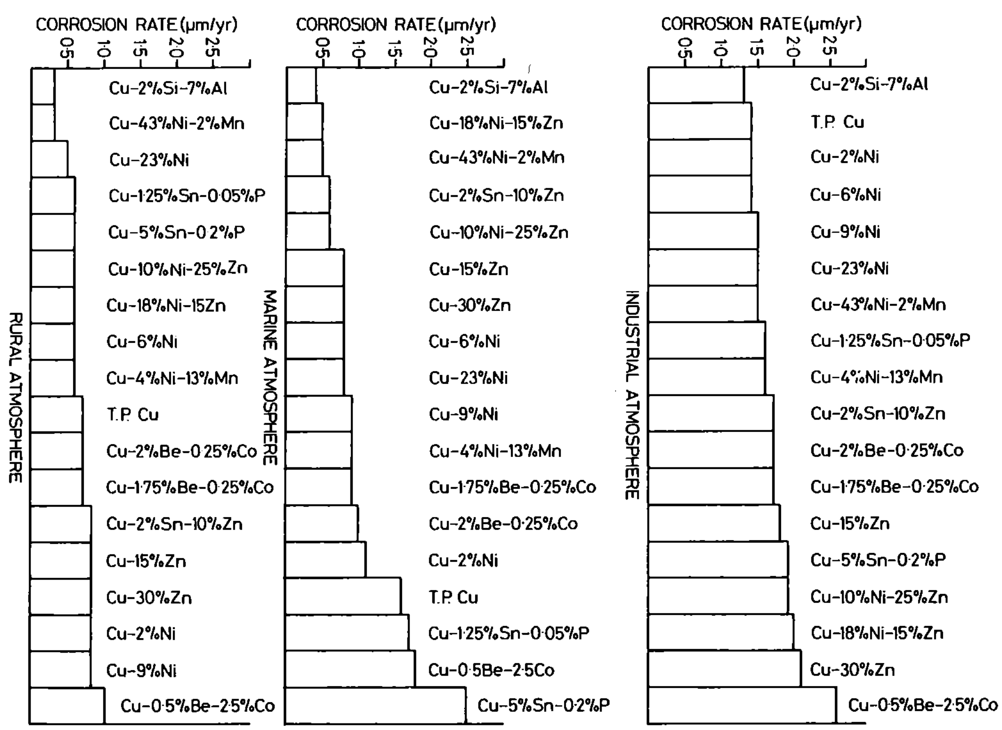
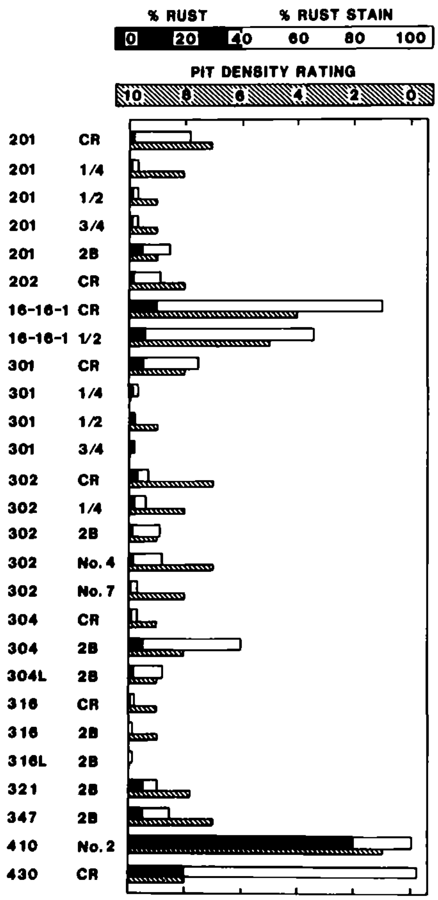
Copper. Effect of initial atmospheric exposure conditions on subsequent corrosion of copper. A = sulfur content of air; B = specimens put out in summer; C = specimens put out in winter. Source: G. Wranglen, *An Introduction to Corrosion and Protection of Metals*, Chapman Hall, New York, 1985, 123.



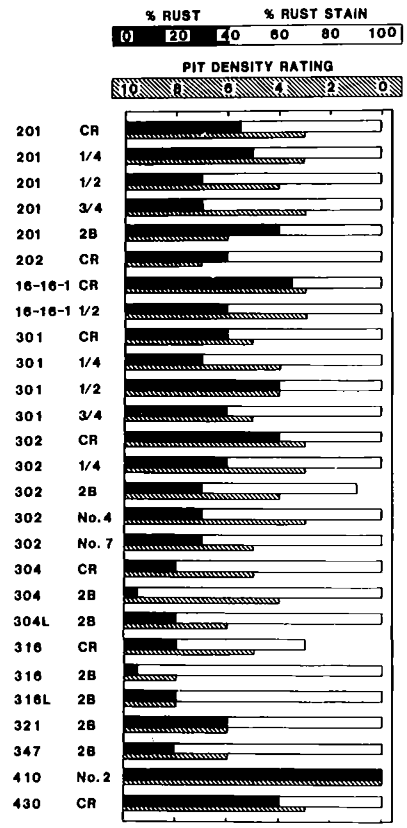
Copper. General corrosion rates for copper and copper alloys in the atmosphere, sloping surfaces. A = low-alloyed copper; B = low-zinc brass; C = high-zinc brass; D = nickel silver; E = tin bronze. Source: V. Kucera and E. Mattson, "Atmospheric Corrosion," in *Corrosion Mechanisms*, F. Mansfeld, Ed., Marcel Dekker, New York, 1987, 274.



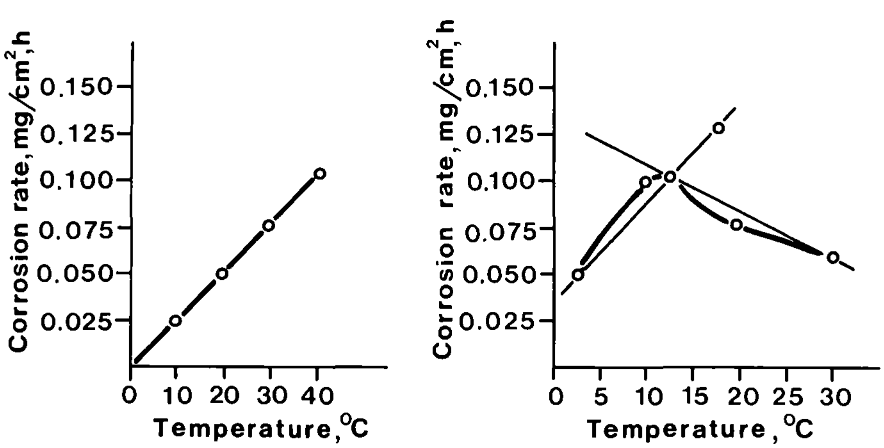
Copper. Average corrosion rates for copper alloys during 7 years of atmospheric exposure. Source: V.E. Carter, "Atmospheric Corrosion of Non-Ferrous Metals," in *Corrosion Processes*, R. Parkins, Ed., Allied Science Publishers, London, 1982, 101.



Stainless steel. Relative performance of stainless steels exposed 250 m from the ocean for 26 years. Source: E.A. Baker and T.S. Lee, "Long-Term Atmospheric Corrosion Behavior of Various Grades of Stainless Steel," *Degradation of Metals in the Atmosphere* (STP 965), S.W. Dean and T.S. Lee, Ed., ASTM, Philadelphia, 1987, 63.

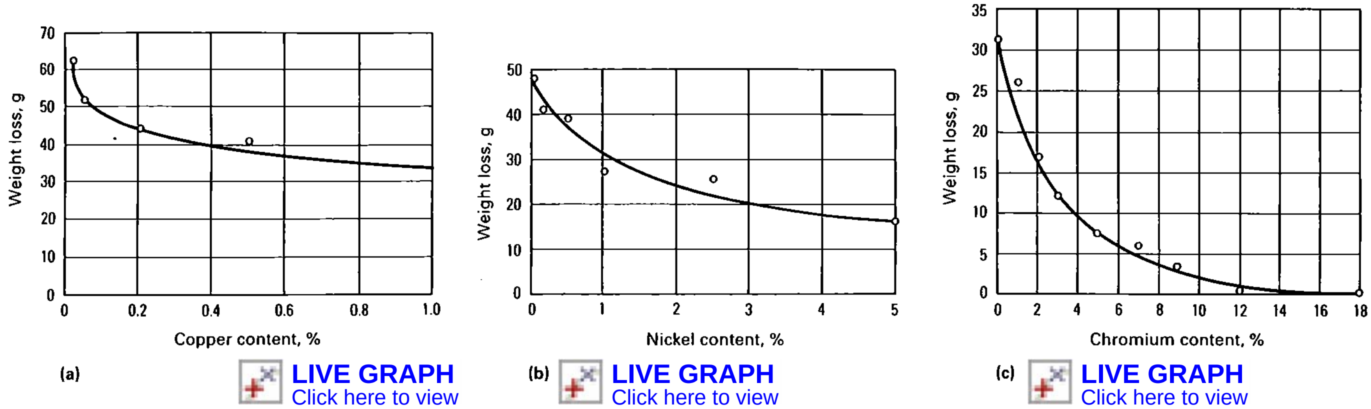


Stainless steel. Relative performance of stainless steels exposed 25 m from the ocean for 26 years. Source: E.A. Baker and T.S. Lee, "Long-Term Atmospheric Corrosion Behavior of Various Grades of Stainless Steel," *Degradation of Metals in the Atmosphere* (STP 965), S.W. Dean and T.S. Lee, Ed., ASTM, Philadelphia, 1987, 62.

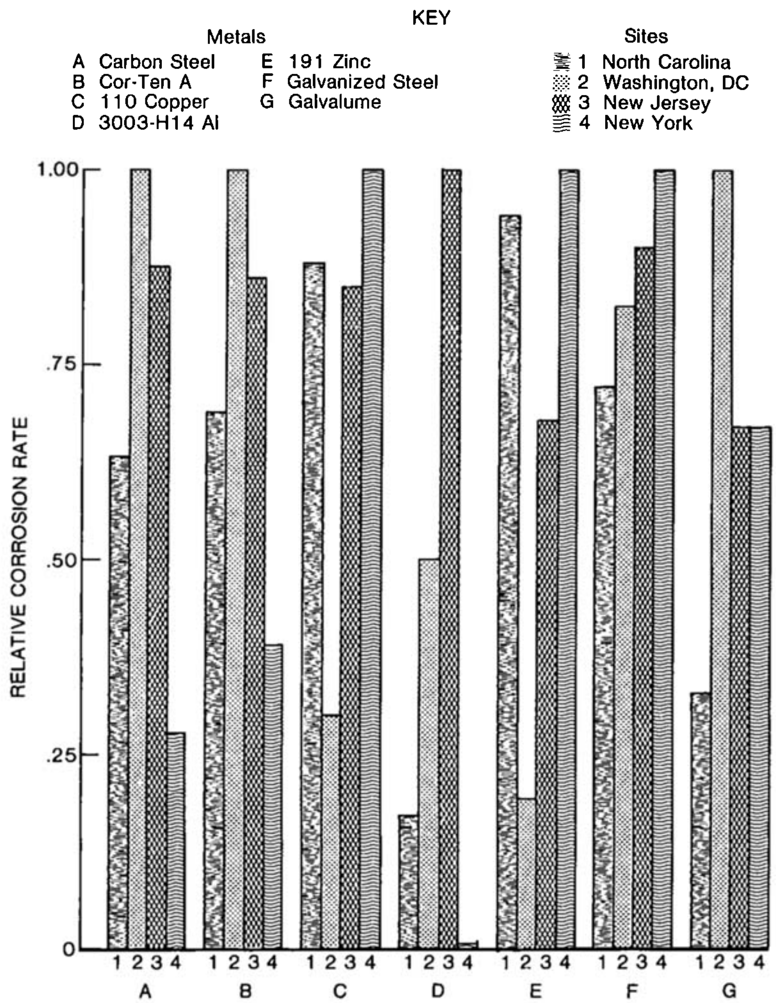


(a) LIVE GRAPH Click here to view (b)

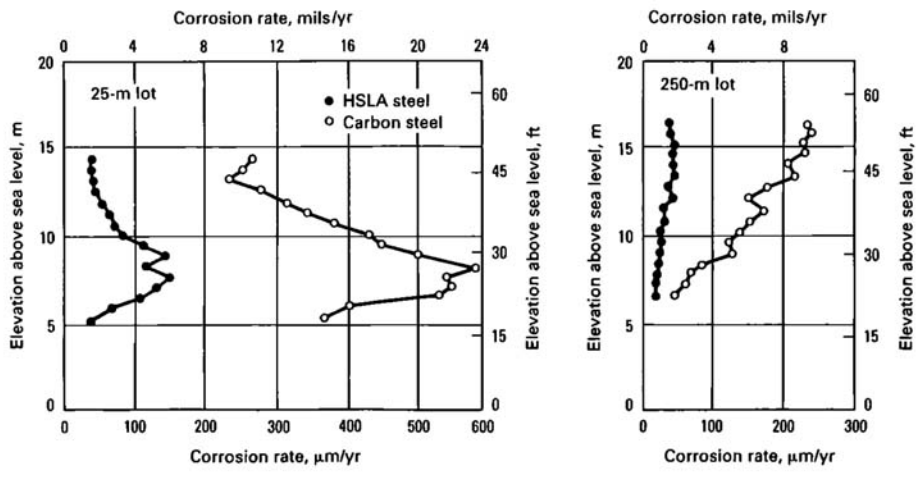
Steels. Influence of air temperature on the atmospheric corrosion rate of carbon steel (a) during rain, and (b) at drying-out of a film of water at a constant relative humidity of 75%. Source: V. Kucera and E. Mattsson, "Atmospheric Corrosion," in *Corrosion Mechanisms*, F. Mansfield, Ed., Marcel Dekker, New York, 1987, 225.



Steels. Effect of alloying additions on the corrosion of steel in a marine atmosphere at Kure Beach, NC (90-month exposure). (a) Effect of copper on 100 by 150 mm specimen. (b) Effect of nickel on 100 by 150 mm specimen. (c) Effect of chromium on 75 by 150 mm specimen. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 540.



Steels, copper, and zinc. Relative annual average monthly corrosion rates for five metals and two coated steels at four materials exposure sites in 1983. Average monthly corrosion rates for a given metal were normalized by dividing by the maximum annual average measured at the four sites. Source: D.R. Flinn, S.D. Cramer, *et al.*, "Field Exposure Study for Determining the Effects of Acid Deposition on the Corrosion and Deterioration of Materials: Description of the Program and Preliminary Results," *Durability of Building Materials*, Vol 3, 1985, 168.



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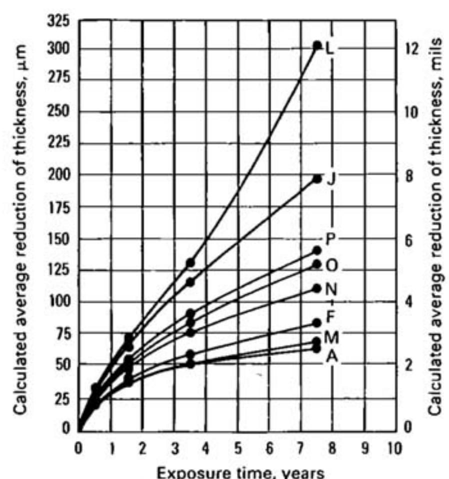
High-strength low-alloy steels. Effect of elevation above sea level for carbon and HSLA steels at Kure Beach, NC. (a) 25-m (80-ft) lot. (b) 250-m (800-ft) lot. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 910.



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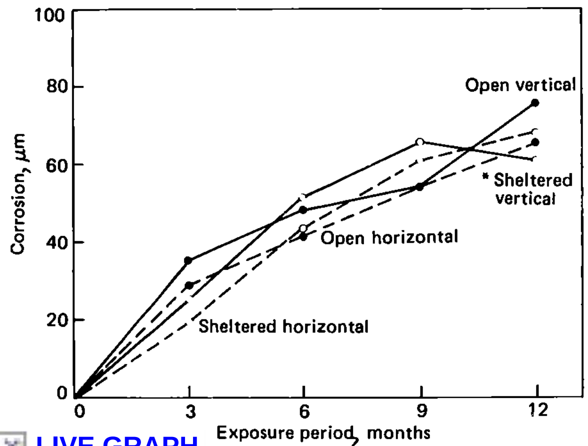
Steel	Composition, % C	Mn	P	S	Si	Cu	Ni	Cr
A(a)	0.09	0.24	0.15	0.024	0.80	0.43	0.05	1.1
M(a)	0.06	0.48	0.11	0.030	0.54	0.41	0.51	1.0
F(a)	0.05	0.36	0.05	0.016	0.008	1.1	2.0	0.01
N(a)	0.11	0.55	0.08	0.026	0.06	0.55	0.28	0.31
O(a)	0.16	1.4	0.013	0.021	0.18	0.30	0.50	0.03
P(a)	0.23	1.5	0.018	0.021	0.19	0.29	0.04	0.08
J(b)	0.19	0.52	0.008	0.039	0.01	0.29	0.05	0.05
L(b)	0.16	0.42	0.013	0.021	0.01	0.02	0.02	0.01

(a) High-strength low-alloy steels. (b) Structural carbon and structural copper steels

Steels. Effect of exposure time on corrosion of steels in marine atmosphere at Kure Beach, NC. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 541.



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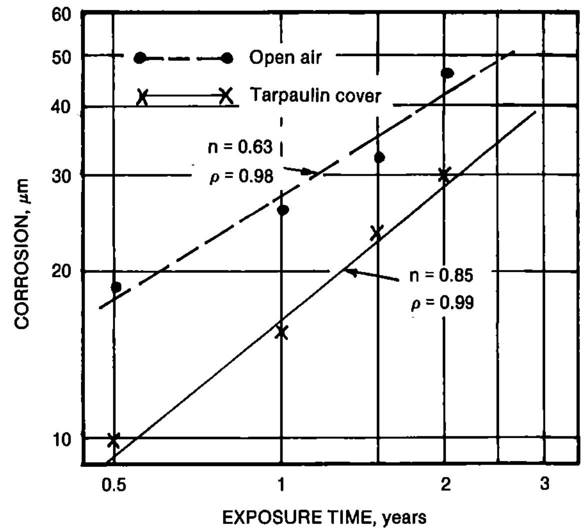
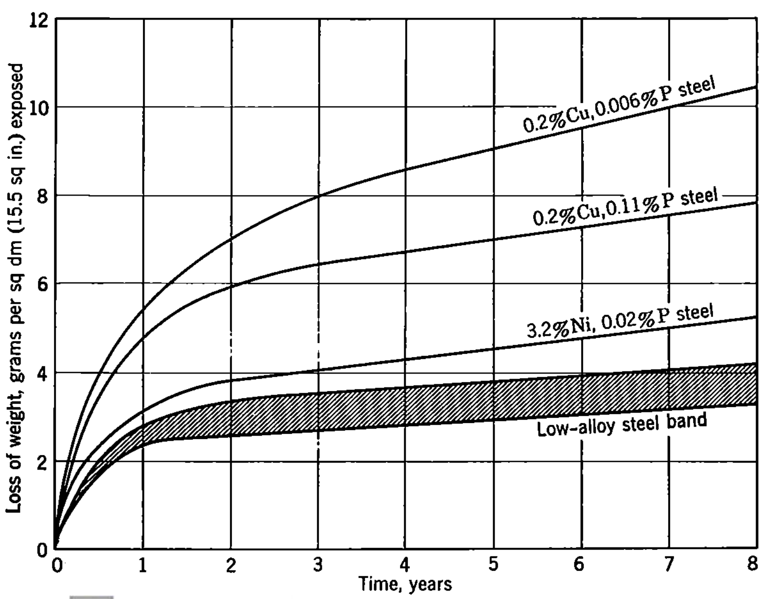
Carbon steels. Corrosion-time curves from Thorney Island specimens; weight loss coupon data; curve marked * shows lower apparent corrosion after 12 months exposure than after 9 months. Source: M. McKenzie and P.R. Vassie, "Use of Weight Loss Coupons and Electrical Resistance Probes in Atmospheric Corrosion Tests," *British Corrosion Journal*, Vol 20, April 1985, 123.



Steels. Relationship between corrosion and exposure time for mild steel under tarpaulin cover and in the open air. Source: O.E. Okarafor, "Corrosion Under Sheltered and Unsheltered Sites in Awka, Nigeria," *Corrosion Prevention and Control*, Vol 33, June 1986, 67.



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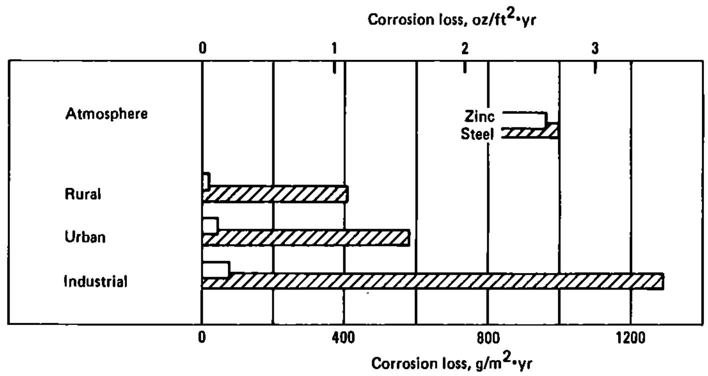
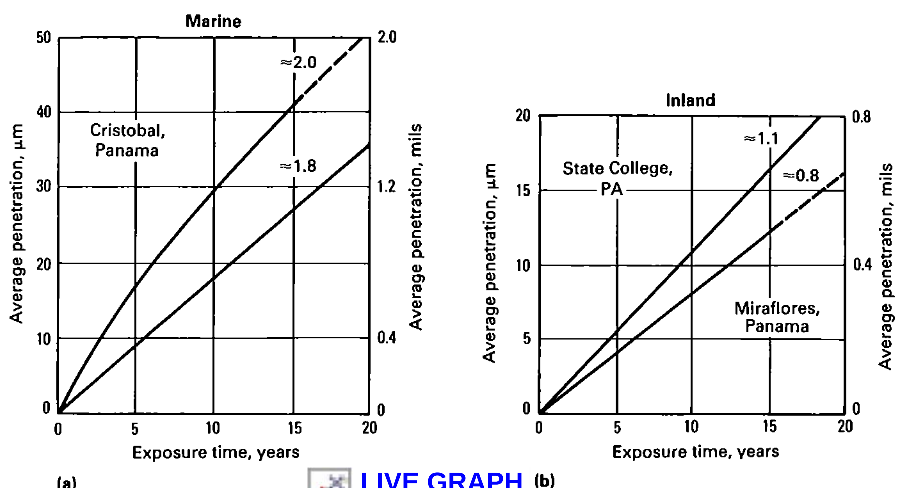
Low-alloy steels. Atmospheric corrosion of steels as a function of time (industrial atmosphere). Source: H.H. Uhlig, *Corrosion and Corrosion Engineering: An Introduction to Corrosion Science and Engineering*, 1st ed., John Wiley & Sons, New York, 1963, 140.



Zinc. Corrosion losses of uncoated steel and zinc in various atmospheres. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 646.



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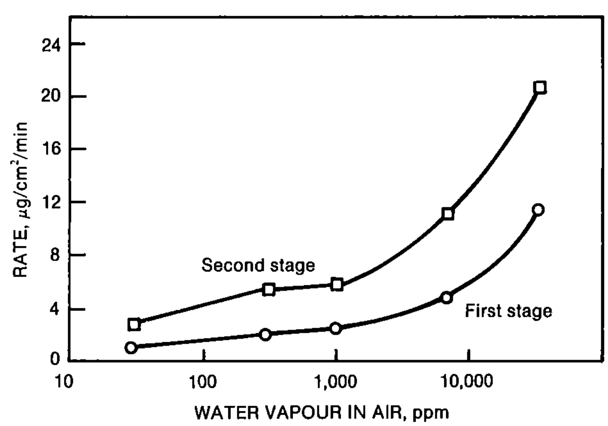
Zinc. Comparison of corrosion rates for zinc at tropical and temperate exposure sites. Numbers on curves are stabilized corrosion rates in microns per year. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 912.



Uranium. Effect of water vapor on reaction of uranium (1-cm cubes) in air at 200 °C. Source: J.H. Gittus, *Uranium*, Butterworths, Washington, 1963, 396.

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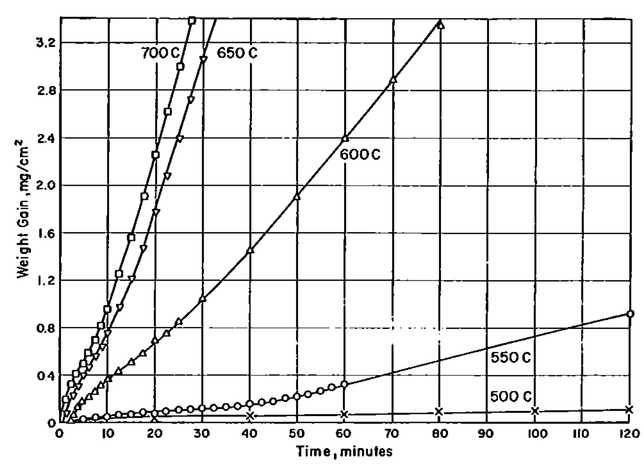

Tantalum. Reaction of tantalum with air at various temperatures. Source: C.A. Hampel, "Tantalum," in *Rare Metals Handbook*, 2nd ed., C.A. Hampel, Ed., Reinhold Publishing, New York, 1961, 503.

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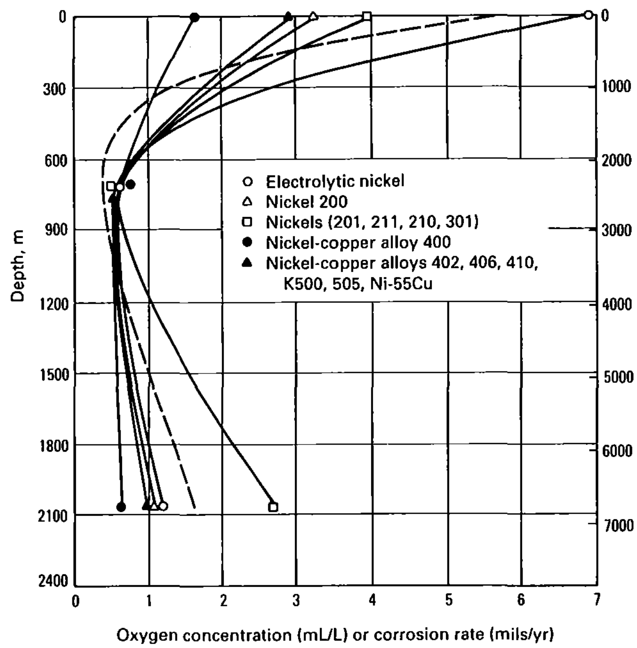

Nickels and nickel coppers. Corrosion of nickels and nickel-copper alloys versus depth after 1 year of exposure compared to the shape of the dissolved oxygen profile (dashed line). Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 904.

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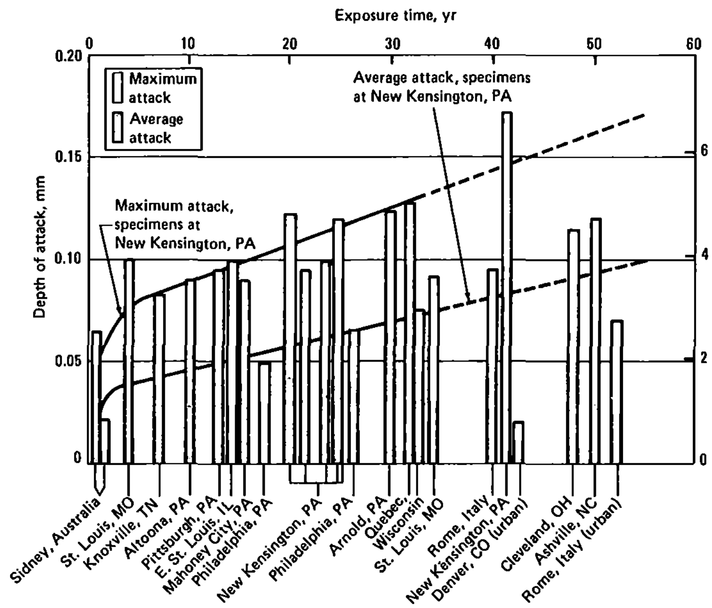
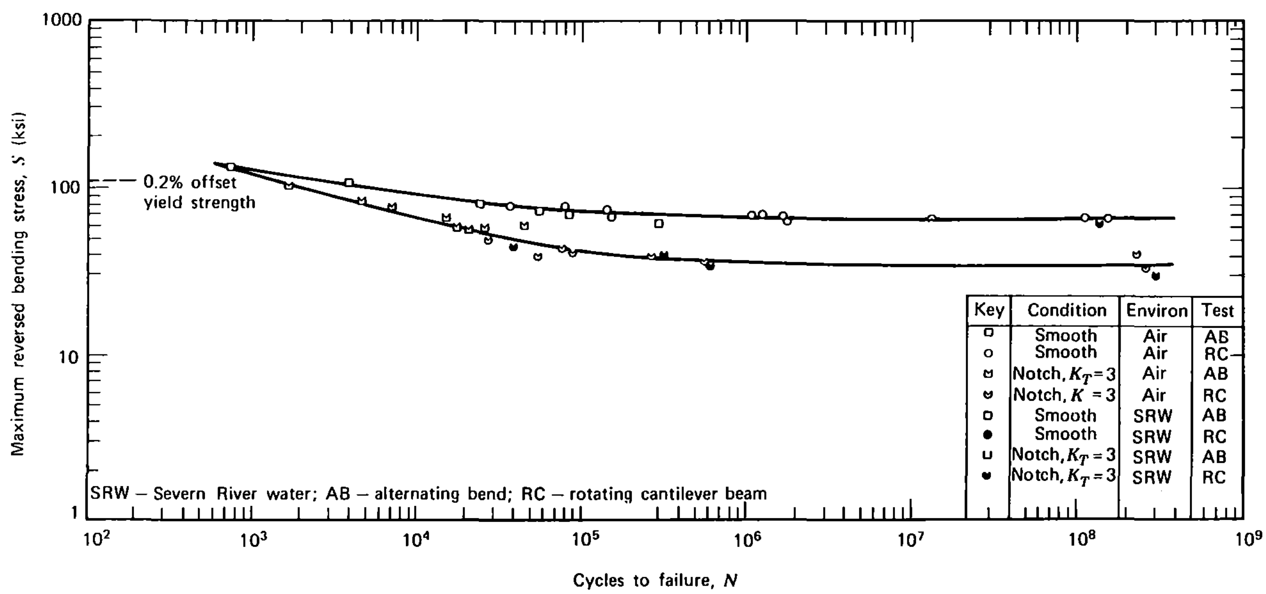


Aluminum. Correlation of weathering data for specimens of alloys 1100, 3003 and 3004, all in H14 temper, exposed in industrial atmosphere (curves) with service experience with aluminum alloys in various locations (bars). Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 222.



Titanium. Corrosion fatigue for Ti-6Al-4V in Severn River water at the U.S. Navy Marine Engineering Laboratory. Source: F.L. LaQue, *Marine Corrosion: Causes and Prevention*, John Wiley & Sons, New York, 1975, 226.

Barium Carbonate

Barium carbonate, $BaCO_3$, also known as witherite, is a white powder that is soluble in acids, with the exception of sulfuric acid. It has a melting point of 174 °C and is used in television picture tubes, rodenticide, optical glass and ceramic flux.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory conditions of 100% relative humidity and ambient temperature, aluminum alloy 3003 was resistant to solid barium carbonate.

Corrosion Behavior of Various Metals and Alloys in Barium Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
AM-363	S36300	...	...	...	Room	...	Resistant	...	120

Barium Chloride

Barium chloride, $BaCl_2$, is a colorless toxic salt with a melting point of 963 °C. It is soluble in water. Barium chloride is used in metal surface treatment and as a rat poison.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory test conditions of 100% relative humidity and ambient temperature, aluminum alloy 3003 was resistant to solid barium chloride. Aluminum alloy 1100 resisted 0.001 to 0.4*N* solutions of barium chloride at ambient temperature.

Corrosion Behavior of Various Metals and Alloys in Barium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel silver	...	...	...	...	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	10	24-100 (75-212)	...	0.5 (20) max	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	9
Nickel and alloys									
Alloy 825	N08825	...	Coal by-product processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus trace sulfide, hydrochloric acid excess, pH 2-3	20	80 (176)	28 d	1.1 (42)	Severe pitting	89
Hastelloy alloy S	N06635	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	0.1 (40)	...	73
Hastelloy alloy X	N06002	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	0.97 (38)	...	73
Haynes alloy 214	...	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	1.8 (71)	...	73
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	10	80 (176)	42 d	0.003 (0.1) max	Pitting occurred after 42 d	44
Inconel 600	N06600	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	2.4 (96)	...	73
Inconel 601	N06601	...	...	10	80 (176)	30 d	0.002 (0.1)	Pitting attack	64
Refractory metals and alloys									
Haynes alloy 188	R30188	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	0.69 (27)	...	73

(Continued)

Corrosion Behavior of Various Metals and Alloys in Barium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes alloy 556	R30556	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	0.11 (44)	...	73
Multimet	R30155	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	0.75 (30)	...	73
Titanium	...	...	...	5	100 (212)	...	Resistant	...	90
Titanium	...	...	...	20	100 (212)	...	Resistant	...	90
Titanium	...	...	...	25	100 (212)	...	Resistant	...	90
Zr702	R60702	...	...	5	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	20	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	25	Boiling	...	0.25 (10) max	...	15
Stainless steels									
301	S30100	...	...	...	...	...	Poor	...	253
301	S30100	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	Saturated solution	Boiling	...	Good	Pitting	253
302	S30200	...	...	...	...	...	Poor	...	253
302	S30200	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	Saturated solution	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	...	...	Poor	...	253
303	S30300	...	...	...	...	...	Poor	...	253
303	S30300	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated solution	Boiling	...	Good	Pitting	253
303	S30300	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
304	S30400	...	...	...	...	...	Poor	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	Saturated solution	Boiling	...	Good	Pitting	253
304	S30400	...	Chemical processing; lab test. Solution repeatedly evaporated	30	100 (212)	4 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; lab test. With carbon over the standard maximum. Plus saturated water solution	...	Room	4 d	0.003 (0.1) max	...	89
304	S30400	...	Coal by-product processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus trace sulfide, hydrochloric acid excess, pH 2-3	20	80 (176)	28 d	6.3 (250)	Severe pitting	89
304	S30400	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	1.9 (75)	...	73
304L	S30403	...	...	...	...	...	Poor	...	253
304L	S30403	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	Saturated solution	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	...	...	...	Poor	...	253
304LN	S30453	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	Saturated solution	Boiling	...	Good	Pitting	253
310	S31000	...	Plus KCl and NaCl. Average metal affected=metal loss+internal penetration	...	845 (1550)	30 d	2.0 (79)	...	73
316	S31600	...	...	...	...	...	Poor	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Barium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus free chlorine, water solution, pH 1	25	35 (95)	11 d	1.3 (52)	Severe pitting	89
316	S31600	...	Coal by-product processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus trace sulfide, hydrochloric acid excess, pH 2-3	20	80 (176)	28 d	4.0 (160)	Severe pitting	89
316F	S31620	...	...	...	...	...	Poor	...	253
316F	S31620	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	Saturated solution	Boiling	...	Good	Pitting	253
316L	S31603	...	...	...	...	...	Poor	...	253
316L	S31603	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	...	...	...	Poor	...	253
316LN	S31653	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	...	...	Poor	...	253
316Ti	S31635	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	...	...	...	Poor	...	253
317L	S31703	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	...	...	...	Poor	...	253
317LN	S31725	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	...	...	...	Poor	...	253
321	S32100	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	Saturated solution	Boiling	...	Good	Pitting	253
329	S32900	...	...	...	...	...	Poor	...	253
329	S32900	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	...	...	...	Poor	...	253
347	S34700	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	Saturated solution	Boiling	...	Good	Pitting	253
403	S40300	...	...	...	...	...	Poor	...	253
403	S40300	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
403	S40300	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
405	S40500	...	...	...	...	...	Poor	...	253
405	S40500	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
405	S40500	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
409	S40900	...	...	...	...	...	Poor	...	253
409	S40900	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
409	S40900	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
410	S41000	...	...	...	...	...	Poor	...	253
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	10	21 (70)	...	Questionable	...	121
410	S41000	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
410	S41000	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
416	S41600	...	...	...	...	...	Poor	...	253
416	S41600	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
416	S41600	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
420	S42000	...	...	...	...	...	Poor	...	253
420	S42000	...	...	Saturated solution	20 (68)	...	Good	Pitting	253
420	S42000	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Barium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	...	...	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
430	S43000	...	...	Saturated solution	Boiling	...	Questionable	Pitting	253
434	S43400	...	...	...	...	...	Poor	...	253
434	S43400	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	Saturated solution	Boiling	...	Good	Pitting	253
F51	S31803	...	...	...	...	...	Poor	...	253
F51	S31803	...	...	Saturated solution	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	Saturated solution	Boiling	...	Resistant	Pitting	253

Barium Hydroxide

Barium hydroxide, $Ba(OH)_2 \cdot 8H_2O$, is a colorless solid composed of monoclinic crystals. It has a melting point of 78 °C and is soluble in water and insoluble in acetone. It is used in the fusion of silicates and fat saponification.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aqueous solutions of barium hydroxide are very corrosive to aluminum alloys in laboratory tests. Therefore, aluminum alloys are not used to service barium hydroxide.

Corrosion Behavior of Various Metals and Alloys in Barium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Barium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Resistant	...	253
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Resistant	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Resistant	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Resistant	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Barium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Barium Nitrate

Barium nitrate, $Ba(NO_3)_2$ forms white crystals that are soluble in water at 20 °C. It is formed by the reaction of barium carbonate or barium hydroxide with nitric acid.

Corrosion Behavior of Various Metals and Alloys in Barium Nitrate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	Boiling	...	Resistant	...	253
405	S40500	...	...	All concentrations	Boiling	...	Resistant	...	253
409	S40900	...	...	All concentrations	Boiling	...	Resistant	...	253
410	S41000	...	...	All concentrations	Boiling	...	Resistant	...	253
416	S41600	...	...	All concentrations	Boiling	...	Resistant	...	253
420	S42000	...	...	All concentrations	Boiling	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Benzene

Benzene, C_6H_6, also known as benzol, phenyl hydride, phene, cyclohexatriene and coal naptha, is a colorless, flammable liquid. It is an aromatic hydrocarbon that boils at 80.1 °C. It is used as a solvent and an intermediate in manufacturing organic compounds such as styrene and phenol.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003, 5052, 5154, and 6061 are resistant to benzene at ambient temperature and at 50 °C (122 °F). Laboratory tests show that the addition of moisture increases the corrosive action of benzene on aluminum alloys. Aluminum equipment such as stills, condensers, heat exchangers, and fractionators have been used in servicing benzene.

Corrosion Behavior of Various Metals and Alloys in Benzene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	...	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	0.5 (20) max	...	95
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Refractory metals and alloys									
Titanium	...	...	...	Liquid	Room	...	Resistant	...	90
Titanium	...	...	Plus HCl, NaCl	Vapor	80 (175)	...	0.005 (0.2)	...	20
Titanium	...	...	Plus HCl, NaCl	Liquid	80 (175)	...	0.005 (0.2)	...	20
Titanium	...	...	Traces of HCl	Vapor	80 (176)	...	0.005 (0.2)	...	90

(Continued)

Corrosion Behavior of Various Metals and Alloys in Benzene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	Traces of HCl	Liquid	80 (176)	...	0.005 (0.2)	...	90
Titanium	...	...	Traces of HCl	Liquid	50 (122)	...	0.025 (1)	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 0.5% methylaldehyde, <0.5% formaldehyde, <0.5% methyl formate, plus impurities	98.5	93-104 (200-220)	13 d	0.03 (1.2)	...	89
304	S30400	...	Chemical processing; field or plant test; slight to moderate aeration; rapid agitation. Plus oleum, probably some sulfur dioxide and trioxide (vapors during first 12 h)	...	185 (365)	1.5 d	12 (470)	...	89
304	S30400	...	Chemical processing; field or plant test; slight to moderate aeration; rapid agitation. Plus oleum, probably some sulfur dioxide and trioxide (vapors during first 12 h)	...	185 (365)	1.5 d	11 (430)	...	89
304	S30400	...	Coal by-product processing; field or plant test; slight to moderate aeration; rapid agitation. Plus 4.5% sulfuric acid, impurities from crude benzene (washer)	95	50-60 (122-140)	44 d	1.7 (67)	Severe pitting	89
304	S30400	...	Pharmaceutical processing; field or plant test; slight to moderate aeration; slight to moderate agitation. Plus water	...	21 (70)	42 d	0.003 (0.1) max	Slight pitting	89
304	S30400	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus 1.5% water, 0.04% acetic acid, 0.02% decomposition gases	98.3	77 (170)	275 d	0.003 (0.1)	...	89
304	S30400	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus 1.5% water, 0.04% acetic acid, 0.02% decomposition gases	98.3	77 (170)	275 d	0.003 (0.1)	...	89
304	S30400	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus furnace vapors, water, acetic anhydride, decomposition gases	...	104 (220)	275 d	0.048 (1.9)	...	89
304	S30400	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus furnace vapors, water, acetic anhydride, decomposition gases	...	104 (220)	275 d	0.053 (2.1)	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Benzene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 0.5% methylaldehyde, <0.5% formaldehyde, <0.5% methyl formate, plus impurities	98.5	93-104 (200-220)	13 d	0.018 (0.7)	...	89
316	S31600	...	Chemical processing; field or plant test; slight to moderate aeration; no agitation. Plus 5% hydrochloric acid, 5% water, chlorinated benzene	90	26 (80)	60 d	0.53 (21)	Severe pitting	89
316	S31600	...	Chemical processing; field or plant test; slight to moderate aeration; no agitation. Plus 40% chlorinated benzene, 5% hydrochloric acid, 5% water	50	26 (80)	60 d	0.13 (5.1)	...	89
316	S31600	...	Coal by-product processing; field or plant test; slight to moderate aeration; rapid agitation. Plus 4.5% sulfuric acid, impurities from crude benzene (washer)	95	50-60 (122-140)	44 d	Poor	Severe pitting	89
316	S31600	...	Pharmaceutical processing; field or plant test; slight to moderate aeration; slight to moderate agitation. Plus water	...	21 (70)	42 d	0.003 (0.1)	Slight pitting	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317	S31700	...	Chemical processing; field or plant test; slight to moderate aeration; rapid agitation. Plus oleum, probably some sulfur dioxide and trioxide (vapors during first 12 h)	...	185 (365)	1.5 d	1.9 (77)	...	89
317	S31700	...	Chemical processing; field or plant test; slight to moderate aeration; rapid agitation. Plus oleum, probably some sulfur dioxide and trioxide (vapors during first 12 h)	...	185 (365)	1.5 d	1.8 (73)	...	89
317	S31700	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus furnace vapors, water, acetic anhydride, decomposition gases	...	104 (220)	275 d	0.028 (1.1)	...	89
317	S31700	...	Rayon processing; field or plant test; no aeration; rapid agitation. Plus furnace vapors, water, acetic anhydride, decomposition gases	...	104 (220)	275 d	0.025 (1.0)	...	89
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Benzene (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
Carpenter 20	...	...	Chemical processing; field or plant test; slight to moderate aeration; no agitation. Plus 5% hydrochloric acid, 5% water, chlorinated benzene	90	26 (80)	60 d	0.35 (14)	Severe pitting	89
Carpenter 20	...	...	Chemical processing; field or plant test; slight to moderate aeration; no agitation. Plus 40% chlorinated benzene, 5% hydrochloric acid, 5% water	50	26 (80)	60 d	1.4 (54)	...	89
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Benzoic Acid

Benzoic acid, C_6H_5COOH, also known as benzene carboxylic acid and phenyl formic acid, is a colorless, monoclinic crystalline solid that has a melting point of 122.4 °C and sublimes readily at 100 °C. It is an aromatic carboxylic acid that is slightly soluble in water and moderately soluble in alcohol and ether. It is used as a preservative and its derivatives are valuable in medicine, commerce, and industry.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Tests under laboratory conditions of ambient temperature and 100% relative humidity showed that aluminum alloys 3003 and 5154 were resistant to solid benzoic acid. The production of benzoic acid has taken place in sublimation equipment, hoppers, and piping made of aluminum alloys.

Corrosion Behavior of Various Metals and Alloys in Benzoic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solid	...	...	...	Resistant	...	92
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Benzoic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum-manganese alloys	...	...	...	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...		...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	1.3 (50) min	...	95
Silver	P07010	...	...	All	130 (265)	...	0.05 (2) max	...	4
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	90	138 (280)	...	0.38 (15)	...	22
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	90	138 (280)	...	0.13 (5)	...	22
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Benzoic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Blood

Classified as a major tissue of the human body, blood is a characteristically red, mobile fluid with an average specific gravity of about 1.058. Slightly sticky and somewhat viscous, blood has a viscosity between 4.5 and 5.5 times greater than that of water at the same temperature. Thus, blood flows somewhat more sluggishly than water. The odor of blood is characteristic; the taste is slightly saline. The pH of blood ranges between 7.35 and 7.45. Under normal conditions, the blood circulates through the body at a temperature of 100.4 °F (38.0 °C). This is slightly higher than the body temperature as determined by mouth, 98.6 °F (37.0 °C).

Unlike a simple liquid, such as water, or a simple solution, as salt water, blood is a complex fluid made up of several components each of which is, in turn, extremely complex and even today is fully understood. Many of these substances are solids in suspension. Unlike most simple liquids that are not easily changed when exposed to air or to slight alternations in their environment, the physical biochemical properties of blood undergo marked changes when blood is taken from the body's circulatory system and, for example, placed in a test tube. Separation of blood from its usual environment immediately initiates biochemical processes that alter its properties and cause it to release its components. When removed, blood shortly becomes viscid and forms a soft, jelly like substance, then soon separates into a firm solid mass (clot) and liquid (serum).

Below are listed some of the constituents of blood.

Adenosine	Adenosine triphosphate	Amino acids	Ammonia N
Ascorbic acid	Bicarbonate	Bile acids	Biotin
Carbon dioxide	Cholesterol	Cholesterol esters	Choline
Fat	Fatty acids	Fibrinogen	Fructose
Glucose	Hemoglobin	Mucopolysaccharides	Mucoproteins
Nicotinic acid	Nitrogen	Non-protein nitrogen	Nucleotide
Nucleotide phosphorus	Oxygen	Pantothenic acid	Polysaccharides
Protein	Purines	Pyruvic acid	Riboflavin
Ribonucleic acid	Sphingomyelin	Thiamine	Urea
Urea N	Uric acid	Vitamin A	

Corrosion Behavior of Various Metals and Alloys in Blood

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253

Boric Acid

Boric acid, H_3BO_3, also known as boracic acid, orthoboric acid, and sassolite, is a white solid composed of triclinic crystals with a melting point of 185 °C. It is a derivative of barium oxide and is soluble in water.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests conducted under the conditions of ambient temperature and 100% relative humidity showed that the aluminum alloys 3003 and 5154 resisted attack by solid boric acid. Aqueous solutions of 1 to 15% boric acid at 60 °C (140 °F) did not attack the aluminum alloys 1100, 3003, or 6061 in other tests. Boric acid has been serviced by aluminum alloy equipment such as drying kilns, valves, and tanks.

Cemented Carbides. Corrosion resistance of cemented titanium carbide is excellent in boric acid and somewhat better than cemented tungsten carbide in hydrochloric acid or sulfuric acid.

Titanium. Near nil corrosion rates have been reported for titanium in boric acid service over the full concentration range to temperatures well beyond the boiling point.

Corrosion Behavior of Various Metals and Alloys in Boric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Boric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Refractory metals and alloys									
Lead	L50045	...	...	10-100	24-149 (75-300)	...	0.5 (20) max	...	95
Magnesium	...	...	...	1-5	Room	...	Poor	...	119
Silver	P07010	...	Salt	...	Boiling	...	0.05 (2) max	...	4
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Resistant	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Titanium	...	...	...	10	Boiling	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Good	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Good	...	121
304	S30400	...	Chemical (boric-acid manufacture) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus mixed liquor, sulfates, sulfites, borax, boric acid	...	54-104 (130-220)	45 d	0.12 (4.8)	Severe pitting	89
304	S30400	...	Chemical (boric-acid manufacture) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Plus mixed liquor, sulfates, sulfites, borax, boric acid	...	54-104 (130-220)	45 d	0.03 (1.0)	Moderate pitting	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Boric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Chemical (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Reboiler	2.5	91 (195)	4.5 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical (distillation) processing; field or pilot plant test; no aeration; rapid agitation. With carbon over the standard maximum. Reboiler	2.5	91 (195)	4.5 d	0.005 (0.2)	...	89
304	S30400	...	Chemical processing; lab test; no aeration; no agitation	70	150 (302)	1 d	8.8 (350) max	...	89
304	S30400	...	Chemical processing; lab test; no aeration; no agitation	50	150 (302)	1 d	1.13 (45)	...	89
304	S30400	...	Chemical processing; lab test; no aeration; no agitation	30	150 (302)	1 d	0.63 (25)	...	89
304	S30400	...	Chemical processing; strong aeration; no agitation. Plus solution saturated with sulfur dioxide; boric acid	...	60 (140)	31 d	0.003 (0.1) max	Crevice attack	89
304	S30400	...	Chemical processing; strong aeration; rapid agitation. Boric acid, sublimed, impurities	...	54-104 (130-220)	45 d	0.12 (4.7)	Severe pitting	89
304	S30400	...	Chemical processing; strong aeration; rapid agitation. With carbon over the standard maximum. Boric acid, sublimed, impurities	...	54-104 (130-220)	45 d	0.050 (2.0)	Severe pitting	89
304	S30400	...	Research	~15.7	24 (75)	70 d	0.003 (0.1) max	...	89
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Good	...	121
316	S31600	...	Chemical (boric-acid manufacture) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus mixed liquor, sulfates, sulfites, borax, boric acid	...	54-104 (130-220)	45 d	0.003 (0.1)	...	89
316	S31600	...	Chemical (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Reboiler	2.5	91 (195)	4.5 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; strong aeration; no agitation. Plus solution saturated with sulfur dioxide; boric acid	...	60 (140)	31 d	0.003 (0.1) max	Crevice attack	89
316	S31600	...	Chemical processing; strong aeration; rapid agitation. Boric acid, sublimed, impurities	...	54-104 (130-220)	45 d	0.12 (4.7)	Slight pitting	89
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Boric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	...	...	253
403	S40300	...	...	All concentrations	Boiling	...	Good	...	253
405	S40500	...	...	All concentrations	20 (68)	...	...	...	253
405	S40500	...	...	All concentrations	Boiling	...	Good	...	253
409	S40900	...	...	All concentrations	20 (68)	...	...	...	253
409	S40900	...	...	All concentrations	Boiling	...	Good	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	All concentrations	20 (68)	...	...	...	253
410	S41000	...	...	All concentrations	Boiling	...	Good	...	253
410	S41000	...	...	Saturated	Boiling	...	Questionable	...	121
416	S41600	...	...	All concentrations	20 (68)	...	...	...	253
416	S41600	...	...	All concentrations	Boiling	...	Good	...	253
420	S42000	...	...	All concentrations	20 (68)	...	...	...	253
420	S42000	...	...	All concentrations	Boiling	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Good	...	253
430	S43000	...	...	Saturated	Boiling	...	Questionable	...	121
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Bromine

Bromine, Br, is a chemical nonmetallic element. It is a dark red liquid that volatilizes at room temperature into a brown irritating vapor. Bromine is a member of the halogen series and has a boiling point of 58.78 °C. It is chemically reactive, has bleaching action, and is used in plastics, organic synthesis, and to produce dibromide ethylene.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Magnesium. Magnesium resists corrosion from dry bromine at room or slightly elevated temperatures. Even if it contains 0.02% water, dry bromine causes no more attack at its boiling point (58 °C, or 136 °F) than at room temperature. Some attack is observed in the presence of a small amount of water. Magnesium is severely attacked by wet bromine below the dew point of any aqueous phase.

Nickel. In laboratory tests at room temperature, bromine commercially dried with sulfuric acid corroded Nickel 200 at a rate of 0.04 mils/yr.

The corrosion rate of Nickel 200 increased to 2.5 mils/yr when bromine was saturated with water. Bromine vapor did not affect the material.

Niobium. Niobium is an excellent material for equipment to handle liquid bromine, because it resists corrosion even when water saturated. Niobium is unaffected by bromine at 100 °C (212 °F).

Platinum. Platinum is not resistant to either dry or wet bromine.

Palladium. Palladium is attacked by bromine when air is present.

Ruthenium. Saturated aqueous solutions of bromine attack ruthenium slowly.

Silver. Silver is resistant to dry bromine.

Tantalum. Tantalum is not attacked by bromine at ordinary temperatures. It is inert up to 150 °C (300 °F). Bromine does attack tantalum at 300 °C (570 °F). No effect is observed when the bromine is dissolved in solutions of salt or acid.

Tin. Tin is readily attacked by bromine at room temperature.

Titanium. Titanium may be used to handle wet bromine gas environments. Water content is critical because rapid, exothermic, halogenation reactions may occur in a dry environment. The temperature and gas flow rate determine the water content. Due to the low water solubility of liquid bromine, titanium alloys cannot be rendered passive. In bromide solutions, the susceptibility of titanium alloys to crevice corrosion should be considered.

Zirconium. Zirconium is quite resistant to pitting corrosion in bromide solutions.

Corrosion Behavior of Various Metals and Alloys in Bromine

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Structural steel	G10100	...	Liquid bromine	...	22 (72)	30 d	.32 (13)	...	258
Structural steel	G10100	...	Liquid bromine with .01% water	...	22 (72)	30 d	.43 (17)	...	258
Structural steel	G10100	...	Liquid bromine with 0.1% water	...	22 (72)	30 d	.75 (30)	...	258
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Good	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Questionable	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Good	...	93
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Poor	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Poor	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Poor	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Poor	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Poor	...	93
Nickel silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel silver	...	...	Moist	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Good	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Bromine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Phosphor copper	C12200	...	Moist	...	...	...	Good	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	Dry or wet	...	22 (72)	...	Poor	...	250
High purity lead	L50001	...	Dry	...	22 (72)	120 d	.095 (3.7)	...	258
High purity lead	L50001	...	Liquid, with 57 ppm water	...	22 (72)	23 d	.058 (2.3)	...	258
High purity lead	L50001	...	Liquid, with 7 ppm water	...	22 (72)	23 d	.013 (0.5)	...	258
High purity lead	L50001	...	Vapor, with 57 ppm water	...	22 (72)	23 d	.092	...	258
High purity lead	L50001	...	Vapor, with 7 ppm water	...	22 (72)	23 d	.042 (1.7)	...	258
High purity lead	L50001	...	With 10% water	...	22 (72)	46 d	.26 (10.2)	...	258
Iridium	...	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Iridium	...	...	Moist	...	22 (72)	...	.25 (10)	...	250
Iridium	...	...	Saturated, in water	...	22 (72)	...	.003 (0.1) max	...	250
Osmium	...	...	Dry	...	22 (72)	...	4.1 (161)	...	250
Platinum	P04995	...	Dry	...	22 (72)	...	3.5 (138)	...	250
Platinum	P04995	...	Moist	...	22 (72)	...	2.0 (80)	...	250
Rhodium	P05990	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Saturated in water	...	22 (72)	...	.003 (0.1) max	...	250
Ruthenium	...	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Ruthenium	...	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Ruthenium	...	...	Saturated in water	...	22 (72)	...	1.0 (40)	...	250
Silver	P07010	...	Dry	...	22 (72)	...	.05 (2)	...	250
Silver	P07010	...	In glacial acetic acid	...	50 (120)	...	.05 (2)	...	250
Silver	P07010	...	In methanol	...	22 (72)	...	0.5 (20)	...	250
Nickel and alloys									
Alloy 400	N04400	...	0.1% moisture	...	22 (72)	30 d	.05 (2.0)	...	257
Alloy 400	N04400	...	0.1% moisture	...	22 (72)	30 d	.03 (1.2)	...	257
Alloy 400	N04400	...	Dry	...	22 (72)	30 d	.012 (0.47)	...	257
Alloy 400	N04400	...	Liquid bromine with 0.01% water	...	22 (72)	23 d	.046 (1.8)	...	258
Alloy 400	N04400	...	Liquid bromine with 0.1% water	...	22 (72)	23 d	.29 (11.4)	...	258
Alloy 400	N04400	...	Liquid bromine	...	22 (72)	23 d	.012 (.47)	...	258
Nickel 200	N02200	...	0.01% moisture	...	22 (72)	30 d	.00024 (.010)	...	257
Nickel 200	N02200	...	0.1% moisture	...	22 (72)	30 d	.0019 (.07)	...	257
Nickel 200	N02200	...	Dry	...	22 (72)	30 d	.00011 (.04)	...	257
Nickel 200	N02200	...	Liquid bromine with 0.01% water	...	22 (72)	23 d	.024 (.95)	...	258
Nickel 200	N02200	...	Liquid bromine with 0.1% water	...	22 (72)	23 d	.19 (7.5)	...	258
Nickel 200	N02200	...	Liquid bromine	...	22 (72)	23 d	.011 (.43)	...	258
Refractory metals and alloys									
Titanium	...	...	...	Liquid	30 (86)	...	Poor	...	90
Titanium	...	...	Gas, dry	...	21 (70)	...	Poor	...	90
Titanium	...	...	In methyl alcohol	0.05	60 (140)	...	0.03 (1.2)	Cracking possible	90
Titanium	...	...	Moist	Vapor	30 (86)	...	0.003 (0.12) max	...	90
Titanium	...	...	Water solution	...	Room	...	Resistant	...	90
Zr702	R60702	...	...	100-liquid	20 (70)	...	0.25 (10) max	Pitting	15

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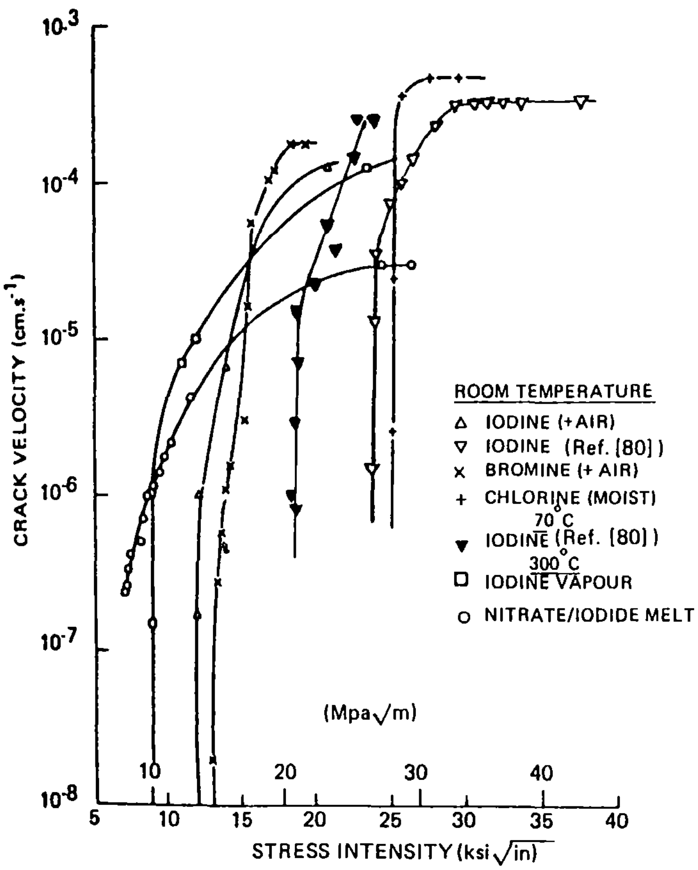
Corrosion Behavior of Various Metals and Alloys in Bromine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zr705	R60705	...	...	100-liquid	20 (70)	...	1.3 (50) max	Pitting	15
Zr705	R60705	...	...	Vapor	20 (70)	...	1.3 (50) min	Pitting	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Poor	Pitting	253
301	S30100	...	...	...	Boiling	...	Poor	Pitting	253
301	S30100	...	...	0.3	20 (68)	...	Good	Pitting	253
301	S30100	...	...	0.33	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	1.0	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	...	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	...	Boiling	...	Poor	Pitting	253
302	S30200	...	...	0.3	20 (68)	...	Good	Pitting	253
302	S30200	...	...	0.33	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	1.0	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	0.3	20 (68)	...	Good	Pitting	253
303	S30300	...	...	0.33	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	1.0	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	Boiling	...	Poor	Pitting	253
304	S30400	...	...	0.3	20 (68)	...	Good	Pitting	253
304	S30400	...	...	0.33	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	1.0	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	...	Boiling	...	Poor	Pitting	253
304L	S30403	...	...	0.3	20 (68)	...	Good	Pitting	253
304L	S30403	...	...	0.33	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	1.0	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	0.3	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	0.33	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	1.0	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	...	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	...	Boiling	...	Poor	Pitting	253
316	S31600	...	...	0.3	20 (68)	...	Good	Pitting	253
316	S31600	...	...	0.33	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	1.0	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	...	Boiling	...	Poor	Pitting	253
316F	S31620	...	...	0.3	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	0.33	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	1.0	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	...	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	0.3	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	0.33	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	1.0	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Poor	Pitting	253

(Continued)

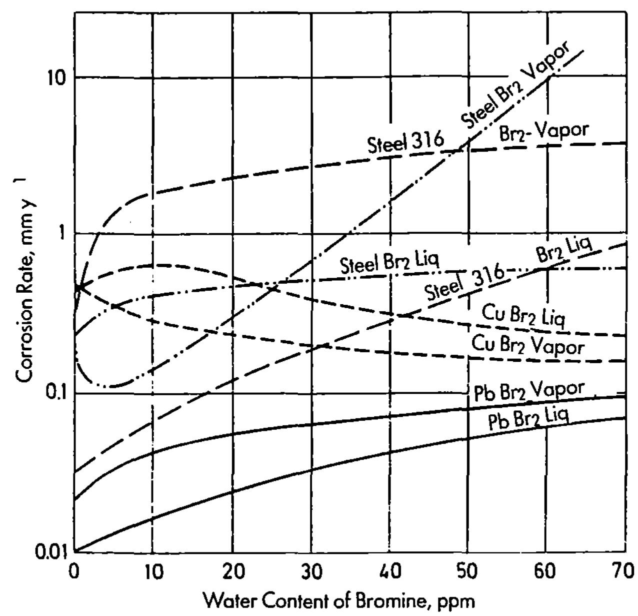
Corrosion Behavior of Various Metals and Alloys in Bromine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	0.3	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	0.33	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	1.0	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Poor	Pitting	253
316Ti	S31635	...	...	0.3	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	0.33	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	1.0	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	...	Boiling	...	Poor	Pitting	253
317L	S31703	...	...	0.3	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	0.33	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	1.0	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Poor	Pitting	253
317LN	S31725	...	...	0.3	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	0.33	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	1.0	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	...	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	...	Boiling	...	Poor	Pitting	253
321	S32100	...	...	0.3	20 (68)	...	Good	Pitting	253
321	S32100	...	...	0.33	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	1.0	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	...	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	...	Boiling	...	Poor	Pitting	253
329	S32900	...	...	0.3	20 (68)	...	Good	Pitting	253
329	S32900	...	...	0.33	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	1.0	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	...	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	...	Boiling	...	Poor	Pitting	253
347	S34700	...	...	0.3	20 (68)	...	Good	Pitting	253
347	S34700	...	...	0.33	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	1.0	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Boiling	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	...	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	...	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	0.3	20 (68)	...	Good	Pitting	253
F51	S31803	...	...	0.33	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	1.0	20 (68)	...	Poor	Pitting	253



Zircaloy. Velocity versus stress intensity curves for Zircaloy in halogen vapors. Ref. 246

LIVE GRAPH
Click here to view



Various alloys. Corrosion rates of copper, chromium-nickel steel and lead in brome at room temperature as a function of water content. Ref. 258

LIVE GRAPH
Click here to view

Butane

Butane, $CH_3(CH_2)_2CH_3$, also known as *n*-butane and methyl-ethyl methane, is a colorless gas that occurs in natural gas and is obtained by cracking petroleum. It is used as a refrigerant and as a fuel.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon Steel. Butane is most often transported and stored in carbon steel piping and equipment.

Aluminum. Butane has been successfully piped in aluminum alloy tubing.

Corrosion Behavior of Various Metals and Alloys in Butane

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butane (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; strong aeration; rapid agitation. Plus 1% carbon dioxide, 2% water, 4% acetic acid, 10% nitrogen, 27% various organics	56	175 (347)	210 d	0.005 (0.2)	...	89
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% water, 0.5% acetic acid, 1% isobutane	98	29 (185)	276 d	Resistant	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% water, 0.5% acetic acid, 1% isobutane	98	29 (185)	276 d	0.008 (0.3)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 3% water, 22% carbonyls and esters, 10% acetic acid	65	52 (125)	108 d	Resistant	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus esters and water, mainly acetic acids, 65% nitrogen	20	171 (340)	108 d	0.075 (3.0)	Severe pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus light hydrocarbons, 0.5% oxygen, 75% nitrogen, acids and esters remainder	20	52 (125)	108 d	Resistant	...	89
304	S30400	...	Petroleum processing; field or pilot plant test; no aeration; no agitation. Plus trace of water, sulfuric acid, dibutyl sulfite, butylene	...	121 (250)	52 d	0.15 (6.0)	Moderate pitting	89
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus carbon dioxide, water, esters, ketones, 1% acetic acid	98	30-45 (86-113)	363 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butane (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus trace aldehydes, esters, ketones, water, nitrogen and carbon dioxide	98	30-45 (86-113)	363 d	0.003 (0.1)	...	89
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus alcohols, ketones, esters, acetone, methyl acetate, methylethyl ketone, ethyl acetate, water	60	55-69 (131-156)	360 d	0.003 (0.1) max	...	89
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus alcohols, ketones, esters, acetone, methyl acetate, methylethyl ketone, ethyl acetate, water	60	55-69 (131-156)	360 d	0.05 (0.2)	...	89
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus alcohols, ketones, esters, acetone, methyl acetate, methylethyl ketone, ethyl acetate, water	60	55-69 (131-156)	360 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% water, 0.5% acetic acid, 1% isobutane	98	29 (185)	276 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% water, 0.5% acetic acid, 1% isobutane	98	29 (185)	276 d	0.004 (0.15)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 3% water, 22% carbonyls and esters, 10% acetic acid	65	52 (125)	108 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Low-carbon grade (0.03% C max). Plus 3% water, 22% carbonyls and esters, 10% acetic acid	65	52 (125)	108 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus esters and water, mainly acetic acids, 65% nitrogen	20	171 (340)	108 d	0.02 (0.8)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Sensitized specimens. Plus esters and water, mainly acetic acids, 65% nitrogen	20	171 (340)	108 d	0.08 (3.0)	Moderate pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus light hydrocarbons, 0.5% oxygen, 75% nitrogen, acids and esters remainder	20	52 (125)	108 d	Resistant	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Low-carbon grade (0.03% C max). Plus light hydrocarbons, 0.5% oxygen, 75% nitrogen, acids and esters remainder	20	52 (125)	108 d	Resistant	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butane (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing; strong aeration; rapid agitation. Plus 1% carbon dioxide, 2% water, 4% acetic acid, 10% nitrogen, 27% various organics	56	175 (347)	210 d	0.008 (0.3)	...	89
316	S31600	...	Petroleum processing; field or pilot plant test; no aeration; no agitation. Plus trace of water,sulfuric acid, dibutyl sulfite, butylene	...	121 (250)	52 d	0.05 (2.0)	Slight pitting	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus carbon dioxide, water, esters, ketones, 1% acetic acid	98	30-45 (86-113)	363 d	0.003 (0.1) max	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus trace aldehydes, esters, ketones, water, nitrogen and carbon dioxide	98	30-45 (86-113)	363 d	0.003 (0.1)	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus alcohols, ketones, esters, acetone, methyl acetate, methylethyl ketone, ethyl acetate, water	60	55-69 (131-156)	360 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Chemical processing; strong aeration; rapid agitation. Plus 1% carbon dioxide, 2% water, 4% acetic acid, 10% nitrogen, 27% various organics	56	175 (347)	210 d	0.008 (0.3)	...	89

Butyl Alcohol

Butyl alcohol, also known as butanol, exists in three isomeric alcohols that are toxic and soluble in most organic liquids. *n*-butyl alcohol, $CH_3(CH_2)_2CH_2OH$, also known as 1-butanol, propyl carbinol, and *prim*-butyl alcohol, is a colorless liquid with a boiling point of 117.71 °C. It is used in manufacturing perfumes and lacquers. *sec*-butyl alcohol, $CH_3CH_2CHOHCH_3$, also known as 2-butanol, ethyl-methyl carbinol, butylene hydrate, and 2-hydroxy butane, is a colorless liquid with a boiling point of 99.5 °C. It is used in the preparation of fruit essence. *tert*-butyl alcohol, $(CH_3)_3COH$, also known as 2-methyl 2-propanol and trimethyl carbinol, is a colorless liquid with a boiling point of 82.8 °C.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. A water-cooled tube of aluminum alloy 3003 was found to resist vapors from *n*-butyl alcohol during laboratory tests. In other tests at 204 °C (400 °F), aluminum alloy 3003 was resistant to *n*-butyl alcohol with 5% water, but was corroded by a solution with 1.5% water. At the same temperature, secondary and tertiary butyl alcohols with 0.3% water did not corrode aluminum alloy 3003. Pure butyl alcohol and butyl alcohol-water mixtures have been handled by aluminum alloy equipment such as decanters, tanks, and heat exchangers.

Corrosion Behavior of Various Metals and Alloys in Butyl Alcohol

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum-manganese alloys	...	...	Liquid	...	20-boiling (68-boiling)	...	Questionable	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 8.5-9% water, 8% higher alcohols, 1-1.5% carbonyls	82	121 (250)	243 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 0.3% carbonyls, esters, trace of heavy alcohols	99	129 (265)	277 d	0.009 (0.35)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 95% water	5	90 (195)	39 d	0.05 (1.8)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 90% water, 5% methyl and ethyl alcohol	5	90 (195)	39 d	0.003 (0.13)	...	89
304	S30400	...	Chemical processing; no aeration; rapid agitation. Plus 8% higher alcohols, 0.5% carbonyls	9	129 (265)	243 d	0.003 (0.1) max	...	89
304	S30400	...	Pharmaceutical processing; strong aeration; no agitation. Plus 3-4% hydrochloric acid	96-97	Room	18 d	0.65 (26)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 90% water, 5% methyl and ethyl alcohol	5	90 (195)	39 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 95% water	5	90 (195)	39 d	0.075 (3.0)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Pharmaceutical processing; strong aeration; no agitation. Plus 3-4% hydrochloric acid	96-97	Room	18 d	0.38 (15)	Moderate pitting	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 90% water, 5% methyl and ethyl alcohol	5	90 (195)	39 d	Resistant	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 95% water	5	90 (195)	39 d	0.05 (2.0)	...	89
AM-363	S36300	...	...	...	Room	...	Resistant	...	120

Butyric Acid

Butyric acid, C_3H_7COOH, a colorless liquid with an obnoxious odor, occurring in spoiled butter. It boils at 165.5 °C; miscible with water, alcohol, and ether. It is used in the synthesis of butyrate ester perfume and flavor ingredients and in disinfectants and pharmaceuticals.

Corrosion Behavior of Various Metals and Alloys in Butyric Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	100	20 (68)	...	Resistant	...	253
301	S30100	...	...	100	Boiling	...	Good	...	253
302	S30200	...	...	100	20 (68)	...	Resistant	...	253
302	S30200	...	...	100	Boiling	...	Good	...	253
303	S30300	...	...	100	20 (68)	...	Resistant	...	253
303	S30300	...	...	100	20 (68)	...	Resistant	...	253
303	S30300	...	...	100	Boiling	...	Good	...	253
303	S30300	...	...	100	Boiling	...	Questionable	...	253
304	S30400	...	...	100	20 (68)	...	Resistant	...	253
304	S30400	...	...	100	Boiling	...	Good	...	253
304L	S30403	...	...	100	20 (68)	...	Resistant	...	253
304L	S30403	...	...	100	Boiling	...	Good	...	253
304LN	S30453	...	...	100	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	100	Boiling	...	Good	...	253
316	S31600	...	...	100	20 (68)	...	Resistant	...	253
316	S31600	...	...	100	Boiling	...	Resistant	...	253
316F	S31620	...	...	100	20 (68)	...	Resistant	...	253
316F	S31620	...	...	100	Boiling	...	Good	...	253
316L	S31603	...	...	100	20 (68)	...	Resistant	...	253
316L	S31603	...	...	100	Boiling	...	Resistant	...	253
316LN	S31653	...	...	100	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	100	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	100	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Butyric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	100	Boiling	...	Resistant	...	253
317L	S31703	...	...	100	20 (68)	...	Resistant	...	253
317L	S31703	...	...	100	Boiling	...	Resistant	...	253
317LN	S31725	...	...	100	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	100	Boiling	...	Resistant	...	253
321	S32100	...	...	100	20 (68)	...	Resistant	...	253
321	S32100	...	...	100	Boiling	...	Good	...	253
329	S32900	...	...	100	20 (68)	...	Resistant	...	253
329	S32900	...	...	100	Boiling	...	Resistant	...	253
347	S34700	...	...	100	20 (68)	...	Resistant	...	253
347	S34700	...	...	100	Boiling	...	Good	...	253
403	S40300	...	...	100	Boiling	...	Questionable	...	253
405	S40500	...	...	100	Boiling	...	Questionable	...	253
409	S40900	...	...	100	Boiling	...	Questionable	...	253
410	S41000	...	...	100	Boiling	...	Questionable	...	253
416	S41600	...	...	100	Boiling	...	Questionable	...	253
420	S42000	...	...	100	Boiling	...	Questionable	...	253
430	S43000	...	...	100	20 (68)	...	Resistant	...	253
430	S43000	...	...	100	Boiling	...	Questionable	...	253
434	S43400	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	Boiling	...	Resistant	...	253

Cadmium Sulfate

Cadmium sulfate, $CdSO_4$, is an efflorescent crystalline solid that is soluble in water. It is used as an antiseptic, in the treatment of venereal diseases and rheumatism, and to detect the presence of hydrogen sulfide.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests conducted at 100% relative humidity and ambient temperature showed aluminum alloys 3003 and 5154 to be resistant to solid cadmium sulfate. Aluminum alloy 3003 suffered mild attack by an aqueous solution of 1 to 15% cadmium sulfate at ambient temperature. Cadmium sulfate has been handled in aluminum alloy equipment such as filter press plates, pipes, and tanks.

Corrosion Behavior of Various Metals and Alloys in Cadmium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	10-30	24-100 (75-212)	...	0.05 (2) max	...	95
Stainless steels									
304	S30400	...	Chemical processing; lab test; no aeration; no agitation. Alternately immersed	30	100 (212)	4 d	0.013 (0.5)	...	89

Corrosion Behavior of Various Metals and Alloys in Butyric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	100	Boiling	...	Resistant	...	253
317L	S31703	...	...	100	20 (68)	...	Resistant	...	253
317L	S31703	...	...	100	Boiling	...	Resistant	...	253
317LN	S31725	...	...	100	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	100	Boiling	...	Resistant	...	253
321	S32100	...	...	100	20 (68)	...	Resistant	...	253
321	S32100	...	...	100	Boiling	...	Good	...	253
329	S32900	...	...	100	20 (68)	...	Resistant	...	253
329	S32900	...	...	100	Boiling	...	Resistant	...	253
347	S34700	...	...	100	20 (68)	...	Resistant	...	253
347	S34700	...	...	100	Boiling	...	Good	...	253
403	S40300	...	...	100	Boiling	...	Questionable	...	253
405	S40500	...	...	100	Boiling	...	Questionable	...	253
409	S40900	...	...	100	Boiling	...	Questionable	...	253
410	S41000	...	...	100	Boiling	...	Questionable	...	253
416	S41600	...	...	100	Boiling	...	Questionable	...	253
420	S42000	...	...	100	Boiling	...	Questionable	...	253
430	S43000	...	...	100	20 (68)	...	Resistant	...	253
430	S43000	...	...	100	Boiling	...	Questionable	...	253
434	S43400	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	Boiling	...	Resistant	...	253

Cadmium Sulfate

Cadmium sulfate, $CdSO_4$, is an efflorescent crystalline solid that is soluble in water. It is used as an antiseptic, in the treatment of venereal diseases and rheumatism, and to detect the presence of hydrogen sulfide.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests conducted at 100% relative humidity and ambient temperature showed aluminum alloys 3003 and 5154 to be resistant to solid cadmium sulfate. Aluminum alloy 3003 suffered mild attack by an aqueous solution of 1 to 15% cadmium sulfate at ambient temperature. Cadmium sulfate has been handled in aluminum alloy equipment such as filter press plates, pipes, and tanks.

Corrosion Behavior of Various Metals and Alloys in Cadmium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	10-30	24-100 (75-212)	...	0.05 (2) max	...	95
Stainless steels									
304	S30400	...	Chemical processing; lab test; no aeration; no agitation. Alternately immersed	30	100 (212)	4 d	0.013 (0.5)	...	89

Calcium Bisulfite

Now more commonly known as calcium hydrogensulfite, $Ca(HSO_3)_2$ is a compound known only in solution. The colorless aqueous solution smells like sulfur dioxide and is made by dissolving calcium sulfite in aqueous SO_2 solution, or by passing SO_2 through calcium hydroxide suspensions. Used in large amounts to make cellulose by the sulfite process, it is also used to disinfect barns, as an antiseptic in medicine, and as a preservative.

Corrosion Behavior of Various Metals and Alloys in Calcium Bisulfite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Questionable	...	253
301	S30100	...	20 bar	...	200 (392)	...	Poor	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Questionable	...	253
302	S30200	...	20 bar	...	200 (392)	...	Poor	...	253
303	S30300	...	...	...	20 (68)	...	Questionable	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Poor	...	253
303	S30300	...	...	...	Boiling	...	Questionable	...	253
303	S30300	...	20 bar	...	200 (392)	...	Poor	...	253
303	S30300	...	20 bar	...	200 (392)	...	Poor	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Questionable	...	253
304	S30400	...	20 bar	...	200 (392)	...	Poor	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Questionable	...	253
304L	S30403	...	20 bar	...	200 (392)	...	Poor	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Questionable	...	253
304LN	S30453	...	20 bar	...	200 (392)	...	Poor	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	20 bar	...	200 (392)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Questionable	...	253
316F	S31620	...	20 bar	...	200 (392)	...	Poor	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	20 bar	...	200 (392)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	20 bar	...	200 (392)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	20 bar	...	200 (392)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	20 bar	...	200 (392)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	20 bar	...	200 (392)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Bisulfite (Continued)

Material	UNS	Condition		Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...		...	20 (68)	...	Resistant	...	253
321	S32100	...	...		...	Boiling	...	Questionable	...	253
321	S32100	...	20 bar		...	200 (392)	...	Poor	...	253
329	S32900	...	...		...	20 (68)	...	Resistant	...	253
329	S32900	...	...		...	Boiling	...	Resistant	...	253
329	S32900	...	20 bar		...	200 (392)	...	Resistant	...	253
347	S34700	...	...		...	20 (68)	...	Resistant	...	253
347	S34700	...	...		...	Boiling	...	Questionable	...	253
347	S34700	...	20 bar		...	200 (392)	...	Poor	...	253
403	S40300	...	...		...	20 (68)	...	Questionable	...	253
403	S40300	...	...		...	Boiling	...	Poor	...	253
403	S40300	...	20 bar		...	200 (392)	...	Poor	...	253
405	S40500	...	...		...	20 (68)	...	Questionable	...	253
405	S40500	...	...		...	Boiling	...	Poor	...	253
405	S40500	...	20 bar		...	200 (392)	...	Poor	...	253
409	S40900	...	...		...	20 (68)	...	Questionable	...	253
409	S40900	...	...		...	Boiling	...	Poor	...	253
409	S40900	...	20 bar		...	200 (392)	...	Poor	...	253
410	S41000	...	...		...	20 (68)	...	Questionable	...	253
410	S41000	...	...		...	Boiling	...	Poor	...	253
410	S41000	...	20 bar		...	200 (392)	...	Poor	...	253
416	S41600	...	...		...	20 (68)	...	Questionable	...	253
416	S41600	...	...		...	Boiling	...	Poor	...	253
416	S41600	...	20 bar		...	200 (392)	...	Poor	...	253
420	S42000	...	...		...	20 (68)	...	Questionable	...	253
420	S42000	...	...		...	Boiling	...	Poor	...	253
420	S42000	...	20 bar		...	200 (392)	...	Poor	...	253
430	S43000	...	...		...	20 (68)	...	Questionable	...	253
430	S43000	...	...		...	Boiling	...	Poor	...	253
430	S43000	...	20 bar		...	200 (392)	...	Poor	...	253
434	S43400	...	...		...	20 (68)	...	Resistant	...	253
434	S43400	...	...		...	Boiling	...	Questionable	...	253
434	S43400	...	20 bar		...	200 (392)	...	Poor	...	253
F51	S31803	...	...		...	20 (68)	...	Resistant	...	253
F51	S31803	...	...		...	Boiling	...	Resistant	...	253
F51	S31803	...	20 bar		...	200 (392)	...	Resistant	...	253

Calcium Bromide

Calcium bromide, $CaBr_2$, is a colorless crystalline solid with a melting point of 765 °C. It is deliquescent and is soluble in water and absolute alcohol. Calcium bromide is used in medicine. Calcium bromide (hydrated), $CaBr_2 \cdot 3H_2O$, has a melting point of 80.5 °C.

Corrosion Behavior of Various Metals and Alloys in Calcium Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$, 5 wt% $CaCl_2$	10	176 (350)	7 d	1.97 (77.7)	...	180

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Bromide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$, 5 wt% $CaCl_2$	20	176 (350)	7 d	1.33 (52.4)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$, 5 wt% $CaCl_2$	10	176 (350)	14 d	1.087 (42.8)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$, 5 wt% $CaCl_2$	20	176 (350)	14 d	6.55 (25.8)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$	10 wt%	176 (350)	7 d	3.59 (141.3)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$	20 wt%	176 (350)	7 d	1.97 (77.6)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$	10 wt%	176 (350)	14 d	1.32 (52.0)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 20 wt% $ZnBr_2$	20 wt%	176 (350)	14 d	1.181 (46.5)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$, 5 wt% $CaCl_2$	20	176 (350)	7 d	2.06 (81.4)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$, 5 wt% $CaCl_2$	10	176 (350)	7 d	3.009 (118.5)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$, 5 wt% $CaCl_2$	10	176 (350)	14 d	1.73 (68.2)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$, 5 wt% $CaCl_2$	20	176 (350)	14 d	1.13 (44.7)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$	10 wt%	176 (350)	7 d	5.14 (202.5)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$	20 wt%	176 (350)	7 d	2.875 (113.2)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$	10 wt%	176 (350)	14 d	2.908 (114.5)	...	180
Carbon steel	G10100	...	Uninhibited brine, 1000 psi pressure. Plus 30 wt% $ZnBr_2$	20 wt%	176 (350)	14 d	1.49 (58.7)	...	180
Refractory metals and alloys									
Zr702	R60702	...	...	100	100 (212)	...	0.05 (2) max	...	15
Stainless steels									
304	S30400	...	Metal processing (air dehumidification); field or pilot plant test; strong aeration; rapid agitation. With carbon over the standard maximum. Plus 41.97% water, 11.53% lithium bromide, 8.58% calcium chloride, specific gravity 1.56 (under spray nozzles)	37.97	49 (120)	38 d	0.023 (0.9)	Moderate pitting	89
317	S31700	...	Metal processing (air dehumidification); field or pilot plant test; strong aeration; rapid agitation. With carbon over the standard maximum. Plus 41.97% water, 11.53% lithium bromide, 8.58% calcium chloride, specific gravity 1.56 (under spray nozzles)	37.97	49 (120)	38 d	0.035 (1.4)	Severe pitting	89

Corrosion Test Results for Carbon Steel in Different Densities of Calcium Bromide/Zinc Bromide Brines at 21 °C (70 °F)

Density, lb/gal	Corrosion rate, mils/yr				
	1 day	4 days	7 days	14 days	30 days
14.2	0.9	0.7	0.3	0.2	0.3
15.2	2.2	0.6	0.4	0.2	0.1
15.8	0.9	0.5	0.4	0.2	0.1
16.4	2.2	0.6	0.5	0.3	0.1
17.0	2.7	0.6	0.6	0.2	0.1
18.0	2.7	0.5	0.6	0.3	0.1
19.2	2.7	0.7	0.3	0.3	0.1

Note: The 14.2 lb/gal density is $CaBr_2$, and the 19.2 lb/gal density is $ZnBr_2/CaBr_2$. The 19.2 lb/gal brine contained a film-forming amine inhibitor.
Source: Dow Chemical USA

Corrosion Test Results for Carbon Steel in Different Densities of Calcium Bromide/Zinc Bromide Brines at 65 °C (150 °F)

Density, lb/gal	Corrosion rate, mils/yr				
	1 day	4 days	7 days	14 days	30 days
14.2	2.7	2.1	1.7	1.3	1.0
15.2	2.7	0.8	0.5	0.4	0.2
15.8	3.1	0.8	0.7	0.4	0.1
16.4	3.1	0.8	1.1	0.6	0.2
17.0	5.3	0.9	1.0	1.4	0.3
18.0	8.0	1.1	0.8	0.7	0.4
19.2	4.0	1.7	1.7	2.4	1.0

Note: The 14.2 lb/gal density is $CaBr_2$, and the 19.2 lb/gal density is $ZnBr_2/CaBr_2$. The 19.2 lb/gal brine contained a film-forming amine inhibitor.
Source: Dow Chemical USA

Corrosion Test Results for Carbon Steel in Different Densities of Calcium Bromide/Zinc Bromide Brines at 121 °C (250 °F)

Density, lb/gal	Corrosion rate, mils/yr				
	1 day	4 days	7 days	14 days	30 days
14.2	12.0	5.0	2.8	2.3	0.4
15.2	6.7	3.4	7.9	6.4	6.8
15.8	6.2	4.0	4.8	2.8	6.7
16.4	9.8	6.1	9.4	4.2	12.5
17.0	30.2	8.3	8.8	8.3	13.4
18.0	38.7	76.0	...	21.2	50.7
19.2	94.7	102.0	35.0	45.0	66.9

Note: The 14.2 lb/gal density is $CaBr_2$, and the 19.2 lb/gal density is $ZnBr_2/CaBr_2$. The 19.2 lb/gal brine contained a film-forming amine inhibitor.
Source: Dow Chemical USA

Calcium Chloride

Calcium chloride, $CaCl_2$, is colorless deliquescent solid that is soluble in water and ethanol. It is formed from the reaction of calcium carbonate and hydrochloric acid or calcium hydroxide and ammonium chloride. It is used in medicine, as an antifreeze, and as a coagulant.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Under laboratory conditions of 100% relative humidity and ambient temperature, solid calcium chloride caused moderate attack (around 6 mils/yr) on aluminum alloys 3003, 5154, and 6061. Aqueous solutions of concentrations up to 45% caused mild attack with evidence of pitting in other tests at ambient temperature. The addition of sodium dichromate can inhibit the corrosive action of calcium chloride. Aluminum alloy equipment has been used to handle inhibited calcium chloride refrigeration brines. Calcium chloride solutions have been controlled with valves of aluminum alloy 356.0.

Corrosion Behavior of Various Metals and Alloys in Calcium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
4130 steel	G41300	...	Packer fluid, deaerated brine, 400 psi CO_2	30	175	30 d	.14 (5.4)	Crevice attack	207
9 Cu steel	S50400	...	Sweet well production fluid, in equilibrium with 1200 psi CO_2	30	175	30 d	.13 (5.2)	...	207
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	20	24 (75)	...	0.05 (2) max	...	95
Magnesium and alloys	...	...	...	All	Room	...	Poor	...	119
Platinum	P04995	...	...	All	100 (212)	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	100 (212)	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	42 d	0.003 (0.1) max	Pitting occurred after 42 d	44
Inconel 601	N06601	...	...	5	80 (176)	30 d	0.002 (0.1)	Pitting attack	64
Inconel 718	N07718	...	Packer fluid, deaerated brine, 400 psi CO_2	30	175	30 d	.003 (0.1)	...	207
Refractory metals and alloys									
B/C titanium	R58640	...	Packer fluid, deaerated brine, 400 psi CO_2	30	175	30 d	.005 (0.2)	...	207
Hafnium	...	...	...	70	...	10 d	Resistant	...	11
Hafnium	...	...	...	70	...	10 d	Resistant	...	11
Niobium	R04210	...	...	70	Boiling	...	Resistant	...	2
Titanium	...	...	...	5	100 (212)	...	0.005 (0.2)	...	90
Titanium	...	...	...	10	100 (212)	...	0.007 (0.28)	...	90
Titanium	...	...	...	20	100 (212)	...	0.015 (0.6)	...	90
Titanium	...	...	...	55	104 (219)	...	0.001 (0.04)	...	90
Titanium	...	...	...	60	149 (300)	...	0.003 (0.12) max	...	90
Titanium	...	...	...	62	154 (309)	...	0.406 (16.24)	...	90
Titanium	...	...	...	73	175 (347)	...	0.80 (32)	...	90
Titanium, grade 12	R53400	...	Tight crevices pH 3.0	10	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 3.0	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 3.0	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 3.0	10	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	...	62	150 (300)	...	Resistant	...	33
Titanium, grade 7	R52400	...	...	73	177 (350)	...	Resistant	...	33
Titanium, grade 7	R52400	...	Tight crevices pH 3.0	10	Boiling	...	Resistant	...	215
Zr702	R60702	...	...	70	Boiling	...	0.0005 (0.2)	...	62
Zr702	R60702	...	...	5	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	10	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	25	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	75	Boiling	...	0.13 (5) max	...	15
Zr702	R60702	...	BP 162° C (324° F)	70	Boiling	...	0.025 (1) max	...	15

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zr702	R60702	...	Plus 8% NaCl, 0.2% $Ca(OH)_2$	14	79 (175)	...	0.025 (1) max	...	15
Zr705	R60705	...	...	70	Boiling	...	...	...	62
Zr705	R60705	...	BP 162° C (324° F)	70	Boiling	...	0.025 (1) max	...	15
Stainless steels									
13Cr steel	S41000	...	Packer fluid, deaerated brine, 400 psi CO_2	30	175	30 d	.13 (5.3)	...	207
2205	S31803	...	Packer fluid, deaerated brine, 400 psi CO_2	30	175	30 d	.006 (0.25)	...	207
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	...	( ) Boiling	...	Good	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	Boiling	...	Good	Pitting	253
304	S30400	...	Chemical processing (air conditioning and refrigeration); field or pilot plant test; strong aeration; rapid agitation. Calcium and magnesium-chloride brine liquors, 50% total chlorides (evaporator)	...	Boiling	26 d	0.005 (0.2)	Slight pitting	89
304	S30400	...	Chemical processing (air conditioning and refrigeration); field or pilot plant test; strong aeration; rapid agitation. Calcium, magnesium and sodium-chloride brine in 28% concentration.	28	71 (160)	31 d	0.003 (0.1) max	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Calcium-magnesium-chloride bittern, 8.69% magnesium chloride, 1.06% sodium chloride, specific gravity 1.38 (alternately immersed)	28.69	79 (175)	130 d	0.003 (0.1) max	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 1-1.3% sodium chloride, approx. 0.1% calcium hydroxide (evaporator)	~58	165 (330)	31 d	0.05 (2.0)	Slight pitting	89
304	S30400	...	Dairy processing; field or pilot plant test; no aeration; slight to moderate agitation. Calcium chloride cooling brine	...	-12 (10)	372 d	0.003 (0.1)	Slight pitting	89
304	S30400	...	Dairy processing; field or pilot plant test; no aeration; slight to moderate agitation. Cooling brine	~30	-12 (10)	355 d	0.003 (0.1) max	Moderate pitting	89
304	S30400	...	Food processing (air cooling); field or pilot plant test; strong aeration; rapid agitation. Plus 0.0017% sodium bichromate as inhibitor, pH 7-8.5 (in brine-spray air stream, dehumidifier)	21.5	-15 to -16 (3 to 4)	338 d	0.003 (0.1) max	...	89
304	S30400	...	Food processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 0.0017% sodium bichromate as inhibitor, pH 7-8.5 (boiling tank, under spray chamber)	21.5	32-107 (90-225)	337 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253

(Continued)

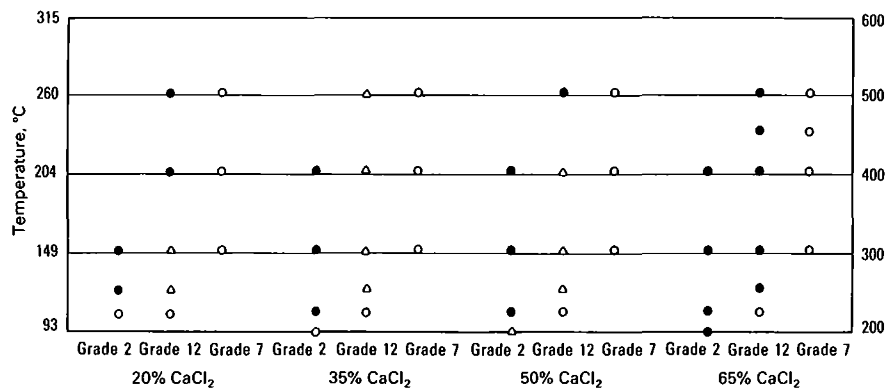
Corrosion Behavior of Various Metals and Alloys in Calcium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	Chemical processing (air conditioning and refrigeration); field or pilot plant test; strong aeration; rapid agitation. Calcium and magnesium-chloride brine liquors, 50% total chlorides (evaporator)	...	Boiling	26 d	0.003 (0.1)	Slight pitting	89
316	S31600	...	Chemical processing (air conditioning and refrigeration); field or pilot plant test; strong aeration; rapid agitation. Calcium, magnesium and sodium-chloride brine	28	71 (160)	31 d	0.003 (0.1) max	Moderate pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Calcium-magnesium-chloride bittern, 8.69% magnesium chloride, 1.06% sodium chloride, specific gravity 1.38 (alternately immersed)	28.69	79 (175)	130 d	0.003 (0.1) max	Moderate pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 1-1.3% sodium chloride, approx. 0.1% calcium hydroxide (evaporator)	~58	165 (330)	31 d	0.043 (1.7)	Slight pitting	89
316	S31600	...	Dairy processing; field or pilot plant test; no aeration; slight to moderate agitation. Calcium chloride cooling brine	...	-12 (10)	372 d	0.003 (0.1)	...	89
316	S31600	...	Dairy processing; field or pilot plant test; no aeration; slight to moderate agitation. Cooling brine	~30	-12 (10)	355 d	0.003 (0.1) max	Moderate pitting	89
316	S31600	...	Food processing (air cooling); field or pilot plant test; strong aeration; rapid agitation. Plus 0.0017% sodium bichromate as inhibitor, pH 7-8.5 (in brine-spray air stream, dehumidifier)	21.5	-15 to -16 (3 to 4)	338 d	0.003 (0.1) max	...	89
316	S31600	...	Food processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 0.0017% sodium bichromate as inhibitor, pH 7-8.5 (boiling tank, under spray chamber)	21.5	32-107 (90-225)	337 d	0.003 (0.1) max	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	Boiling	...	Good	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Good	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	Boiling	...	Good	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Good	Pitting	253

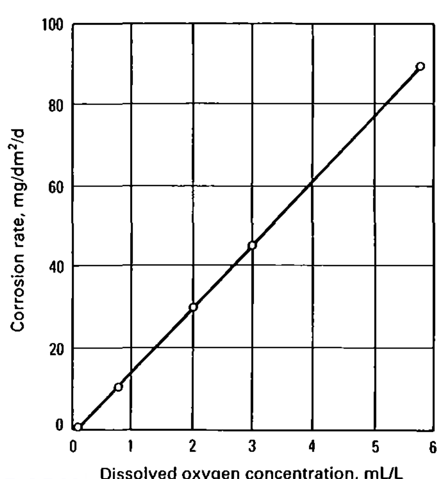
(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	Boiling	...	Good	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	Boiling	...	Good	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	Boiling	...	Good	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
430	S43000	...	...	10	21 (70)	...	Questionable	...	121
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	Boiling	...	Good	Pitting	253



Titanium. Temperature guidelines for avoiding localized attack of grades 2, 7, and 12 titanium in concentrated calcium chloride solutions in the absence of crevices. Closed circle denotes susceptibility to localized attack; open triangle indicates incipient edge attack. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 684.



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Low-carbon steel. Effect of oxygen concentration on the corrosion of low-carbon steel in slowly moving water containing 165 ppm calcium chloride at 24 °C (75 °F). Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 903.

Calcium Fluoride

Calcium fluoride, CaF_2, also known as fluorite and feldspar, is a colorless solid composed of cubic crystals. It has a melting point of 1360 °C. It has a low water solubility, but is readily soluble in ammonium salt solutions. Calcium fluoride is used in the synthesis of hydrofluoric acid and in etching glass.

Corrosion Behavior of Various Metals and Alloys in Calcium Fluoride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	...	24-100 (75-212)	...	0.5 (20) max	...	95
Refractory metals and alloys									
Zr702	R60702	...	pH 5	Saturated	28 (80)	...	Resistant	...	15
Zr702	R60702	...	pH 5	Saturated	90 (195)	...	Resistant	...	15

Calcium Hydroxide

Calcium hydroxide, $Ca(OH)_2$, also known as calcium hydrate and hydrated or slaked lime, is a white solid that is slightly soluble in water. It is used in medicine, construction, and agriculture.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys are rapidly etched by calcium hydroxide solutions in laboratory tests. This action subsides as a protective film forms on the aluminum alloy surface.

Titanium. Titanium alloys are resistant to boiling solutions of calcium hydroxide up to saturation. Although corrosion rates are near nil, titanium alloys under the conditions of temperatures over 80 °C (175 °F) and a pH of 12 or more may experience hydrogen buildup and eventual embrittlement. The addition of dissolved chlorate, hypochlorite, or nitrate compounds in hot caustic solutions can extend resistance to hydrogen uptake to somewhat higher temperatures.

Corrosion Behavior of Various Metals and Alloys in Calcium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-magnesium alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Coppers and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93

(Continued)

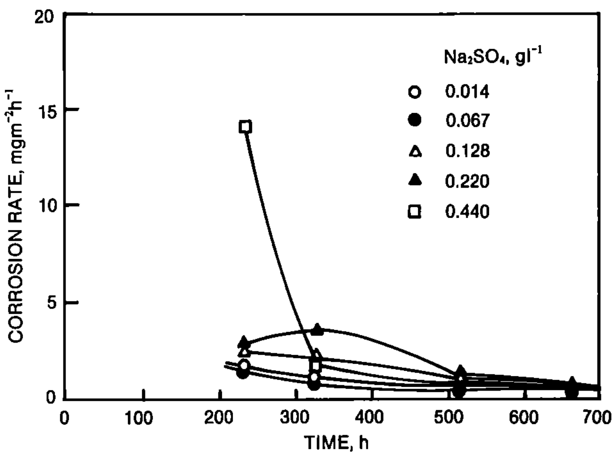
Corrosion Behavior of Various Metals and Alloys in Calcium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Silver	P07010	...	...	All	100 (212)	...	0.05 (2) max	...	9
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Titanium	...	...	...	Saturated	Boiling	...	Resistant	...	90
Titanium	...	...	...	2	100 (212)	...	0.001 (0.04)	...	90
Titanium	...	...	...	6	100 (212)	...	0.001 (0.04)	...	90
Titanium	...	...	...	18	21 (70)	...	Resistant	...	90
Titanium	...	...	...	Saturated	21 (70)	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Calcium hydroxide slurry, some undissolved calcium hydroxide and silica	...	90 (194)	203 d	0.003 (0.1) max	...	89
304	S30400	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus calcium carbonate, sodium hydroxide, sodium sulfide	...	49 (120)	204 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Tanning; field or pilot plant test. Calcium-hydroxide lime liquors, ammonia fumes, sodium sulfide	...	...	180 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus calcium carbonate, sodium hydroxide, sodium sulfide	...	49 (120)	204 d	0.003 (0.1) max	...	89
316	S31600	...	Tanning; field or pilot plant test. Calcium-hydroxide lime liquors, ammonia fumes, sodium sulfide	...	...	180 d	0.003 (0.1) max	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253



Carbon steel. Variation of corrosion rate with time for carbon steel in 0.43 g/L calcium hydroxide solutions containing various concentrations of sodium sulfate. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in Presence of Corrosion Activators," *British Corrosion Journal*, *20*, 34, 1985.

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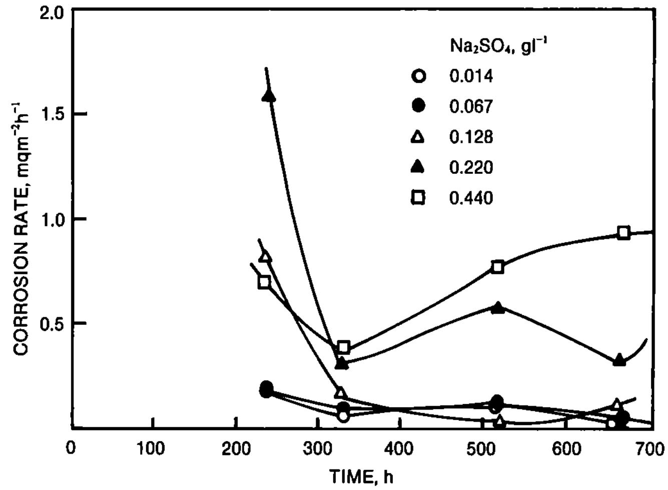

Carbon steel. Variation of corrosion rate with time for carbon steel in 0.76 g/L calcium hydroxide solutions containing various concentrations of sodium sulfate. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in Presence of Corrosion Activators," *British Corrosion Journal*, *20*, 34, 1985.

LIVE GRAPH
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Calcium Hypochlorite

Calcium hypochlorite, $Ca(OCl)_2{\cdot}4H_2O$, also known as calcium oxychloride, chlorinated lime, and bleach, is a deliquescent white powder used as a bleaching agent in the textile and pulp industries and as a disinfectant. It contains 60 to 65% available chlorine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests under the conditions of ambient temperature and 100% relative humidity, solid calcium hypochlorite was corrosive (around 27 mils/yr) to aluminum alloy 3003 and caused moderate attack (around 10 mils/yr) to aluminum alloy 5154. Aqueous solutions, except at very low concentrations, attacked aluminum alloy 3003 in other tests at ambient temperature. Calcium hypochlorite is sometimes handled in aluminum baskets and rotary driers. Occasionally, solid calcium hypochlorite is handled in aluminum, because any corrosive residue does not discolor the product.

Corrosion Behavior of Various Metals and Alloys in Calcium Hypochlorite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
AZ61A	M11610	...	Specimen size, 75 × 25 × 1.5 mm (3 × 1 × 0.06 in.); surface preparation, HNO_3 pickling; volume of testing solution, 100 ml. Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	3.1 (124)	...	12
Platinum	P04995	...	...	All	Room	...	0.05 (2) max	...	5
Nickel and alloys									
Chlorimet 3	...	...	...	18-20	20-24 (70-75)	204 d	0.025 (1)	No pitting	82
Hastelloy C	...	...	...	18-20	20-24 (70-75)	204 d	0.0025 (0.1) max	No pitting	82
Refractory metals and alloys									
Titanium	...	...	...	2	100 (212)	...	0.001 (0.04)	...	27
Titanium	...	...	...	6	100 (212)	...	0.001 (0.04)	...	27
Titanium	...	...	...	18	25 (77)	...	Resistant	...	27
Titanium	...	...	...	18-20	20-24 (70-75)	204 d	Resistant	No pitting	82
Zirconium	R60701	...	...	18-20	20-24 (70-75)	204 d	0.025 (1)	No pitting; severe attack under spacer	82
Zr702	R60702	...	...	2	100 (212)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	6	100 (212)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	20	100 (212)	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	...	Up to 40° (104°)	...	Questionable	...	253
301	S30100	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
301	S30100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	Moist	...	20 (68)	...	Good	Pitting	253
302	S30200	...	...	...	Up to 40° (104°)	...	Questionable	...	253
302	S30200	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
302	S30200	...	Dry	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	Moist	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	Up to 40° (104°)	...	Questionable	...	253
303	S30300	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
303	S30300	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Good	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	Up to 40° (104°)	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
304	S30400	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Moist	...	20 (68)	...	Good	Pitting	253
304L	S30403	...	...	...	Up to 40° (104°)	...	Questionable	...	253
304L	S30403	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
304L	S30403	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	Moist	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	...	Up to 40° (104°)	...	Questionable	...	253
304LN	S30453	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	Moist	...	20 (68)	...	Good	Pitting	253
316	S31600	...	...	...	Up to 40° (104°)	...	Good	...	253
316	S31600	...	...	18-20	20-24 (70-75)	204 d	0.25 (10)	Severe pitting; severe attack under spacer	82
316	S31600	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach slurry, available chlorine 70-100 g/L, lime excess 20-30 g/L	10	32-38 (90-100)	31 d	0.15 (6.0)	Severe pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach slurry, available chlorine 70-100 g/L, lime excess 20-30 g/L	10	32-38 (90-100)	31 d	0.25 (10)	Severe pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach slurry, available chlorine 70-100 g/L, lime excess 20-30 g/L	10	32-38 (90-100)	31 d	0.15 (6)	Severe pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach	~15	24 (75)	65 d	0.30 (12)	Severe pitting	89
316	S31600	...	Chemical processing; lab test	2	100 (212)	...	0.005 (0.2)	...	89
316	S31600	...	Chemical processing; lab test	2	60 (140)	...	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; lab test	6	100 (212)	...	0.013 (0.5)	...	89
316	S31600	...	Chemical processing; lab test	6	36 (97)	...	0.55 (22)	...	89
316	S31600	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Moist	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	...	Up to 40° (104°)	...	Questionable	...	253
316F	S31620	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	Moist	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	...	Up to 40° (104°)	...	Good	...	253
316L	S31603	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Moist	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	...	Up to 40° (104°)	...	Good	...	253
316LN	S31653	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Moist	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	...	Up to 40° (104°)	...	Good	...	253
316Ti	S31635	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	Dry	...	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	Moist	...	20 (68)	...	Good	Pitting	253
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach slurry, available chlorine 70-100 g/L, lime excess 20-30 g/L	10	32-38 (90-100)	31 d	0.58 (23)	Severe pitting	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach slurry, available chlorine 70-100 g/L, lime excess 20-30 g/L	10	32-38 (90-100)	31 d	0.73 (29)	Severe pitting	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Bleach	~15	24 (75)	65 d	0.08 (3.3)	Severe pitting	89
317L	S31703	...	...	...	Up to 40° (104°)	...	Good	...	253
317L	S31703	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Moist	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	...	Up to 40° (104°)	...	Good	...	253
317LN	S31725	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Moist	...	20 (68)	...	Good	Pitting	253
321	S32100	...	...	...	Up to 40° (104°)	...	Questionable	...	253
321	S32100	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
321	S32100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	Moist	...	20 (68)	...	Good	Pitting	253
329	S32900	...	...	...	Up to 40° (104°)	...	Good	...	253
329	S32900	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Dry	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Moist	...	20 (68)	...	Good	Pitting	253
347	S34700	...	...	...	Up to 40° (104°)	...	Questionable	...	253
347	S34700	...	2.5 g Cl/l	...	20 (68)	...	Good	Pitting	253
347	S34700	...	Dry	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	Moist	...	20 (68)	...	Good	Pitting	253
403	S40300	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	Dry	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	Moist	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	Dry	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	Moist	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	Dry	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	Moist	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	Dry	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	Moist	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	Dry	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	Moist	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	Dry	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	Moist	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	2.5 g Cl/l	...	20 (68)	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Calcium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	Dry	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	Moist	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	2.5 g Cl/l	...	20 (68)	...	Questionable	Pitting	253
434	S43400	...	Dry	...	20 (68)	...	Good	Pitting	253
434	S43400	...	Moist	...	20 (68)	...	Questionable	Pitting	253
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation; cast specimens. Bleach	~15	24 (75)	65 d	0.55 (22)	Severe pitting	89
Carpenter 20	...	...	Chemical processing; lab test	2	100 (212)	...	0.003 (0.1)	...	89
Carpenter 20	...	...	Chemical processing; lab test	2	60 (140)	...	0.003 (0.1) max	...	89
Carpenter 20	...	...	Chemical processing; lab test	6	100 (212)	...	0.01 (0.4)	...	89
Carpenter 20	...	...	Chemical processing; lab test	6	36 (97)	...	0.88 (3.5)	...	89
F51	S31803	...	...	...	Up to 40° (104°)	...	Good	...	253
F51	S31803	...	2.5 g Cl/l	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Dry	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Moist	...	20 (68)	...	Good	Pitting	253

Calcium Sulfate

Calcium sulfate, $CaSO_4$, is a grayish-white dense powder that occurs in nature in both an anhydrous form (anhydrite) and hydrated form (gypsum); it is also the byproduct of many chemical reactions. It has many industrial uses; for example, as a source of sulfur and sulfuric acid, in cements, tiles and plaster, as a soil conditioner, in paints, dyes, and polishes, and as a food additive.

Corrosion Behavior of Various Metals and Alloys in Calcium Sulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253

Calcium Sulfite

Calcium sulfite, $CaSO_3 \cdot 0.5H_2O$, is colorless, hexagonal crystals which are nearly insoluble in water. It is formed when sulfur dioxide is passed through a solution of calcium hydroxide, or when solutions of calcium salts and alkali sulfites are mixed. Used as a disinfectant in the sugar industry and breweries, to preserve fruit juices, and as an antichlorine in textile bleaches.

Corrosion Behavior of Various Metals and Alloys in Calcium Sulfite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Camphor

Camphor, $C_{10}H_{16}O$, also known as *d*-2-camphanone, Japan camphor, laurel camphor, Formosa camphor, and gum camphor, is a terpene ketone with a melting point of 175 °C. It is obtained from the wood and bark of the camphor tree and is soluble in water and alcohol. It has two optically active forms (dextro and levo) and an optically inactive mixture (racemic) of these two forms. Camphor is used in pharmaceuticals, in disinfectants, in explosives, and to harden nitrocellulose plastics.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Camphor has been handled successfully in aluminum alloy equipment.

Corrosion Behavior of Various Metals and Alloys in Camphor

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	20-boiling point (68-boiling point)	...	Resistant	...	92
...	...	...	...	...	20-boiling point (68-boiling point)	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Camphor (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Caprylic Acid

Caprylic acid, $CH_3(CH_2)_6COOH$, also known as hexylacetic acid, *n*-octanoic acid, octylic acid, and octic acid, is a liquid fatty acid with a melting point of 16 °C. It is found in butter, coconut oil, and other fats. It is used in manufacturing drugs and dyes.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003 and 5052 were resistant to caprylic acid in limited laboratory tests at ambient temperature. Aluminum alloy tank cars have been used to ship caprylic acid.

Corrosion Behavior of Various Metals and Alloys in Caprylic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon Steel and alloys									
Steel	G10100	...	...	...	Room	...	0.02 (1) max	...	22
Steel	G10100	...	...	...	190 (375)	...	0.89 (35)	...	22

(Continued)

Corrosion Behavior of Various Metals and Alloys in Caprylic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
Copper	...	...	...	...	Room	...	0.02 (1) max	...	22
Copper	...	...	...	...	190 (375)	...	0.02 (1) max	...	22
Silicon bronze	...	...	...	...	Room	...	0.02 (1) max	...	22
Silicon bronze	...	...	...	...	190 (375)	...	0.02 (1) max	...	22
Stainless steels									
304	S30400	...	...	...	Room	...	0.02 (1) max	...	22
304	S30400	...	...	...	190 (375)	...	0.20 (8)	...	22
316	S31600	...	...	...	Room	...	0.02 (1) max	...	22
316	S31600	...	...	...	190 (375)	...	0.02 (1) max	...	22

Carbon

Carbon, C, is a nonmetallic element. It is found in nature as graphite (specific gravity 2.25), diamond (specific gravity 3.51), and coal (specific gravity 1.88). Carbon is found in all living things, is insoluble in common solvents, and forms an almost infinite number of organic compounds. A naturally occurring radioactive isotope, ^{14}C, has a half-life of 5780 years and is used in archaeological investigations to date artifacts and ancient documents. Other uses of carbon depend on its form. For example, diamonds for jewels and abrasives, graphite for lubricants, activated carbon to absorb color and gases, and wood carbon for fuel are some common examples.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Dry carbon does not attack aluminum alloys in laboratory tests. However, corrosion results when wet carbon contacts aluminum, acts as a cathode, and stimulates galvanic action. Aluminum alloy hopper cars have been used with carbon black.

Tantalum. Carbon reacts directly with tantalum at elevated temperatures to form Ta_2C and TaC. Both TaC and Ta_2C have high melting points, metallic appearance, and high hardness.

Corrosion Behavior of Various Metals and Alloys in Carbon

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum 99.0-99.5%	A91199	...	...	...	650 (120) max	...	Resistant	...	92
Nickel and alloys									
825	N08825	...	Chemical processing. Activated carbon "SXAC-L" adsorbing acetone, trace methylene chloride	...	...	57 d	0.003 (0.1) max	...	89
825	N08825	...	Chemical processing. Activated carbon bed "Norit Sorbonorit III" adsorbing acetone containing trace methylene chloride	...	...	57 d	0.003 (0.1)	Slight pitting	89
825	N08825	...	Chemical processing; field or plant test; strong aeration; slight to moderate agitation. Carbon black loose, entrained combustion gases, water vapor, product occasionally on fire	...	49 (120)	324 d	0.010 (0.4)	Slight pitting	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
825	N08825	...	Chemical processing; field or plant test; strong aeration; strong agitation. Carbon- black slurry and water intermittently, pH 7 approx. (water level of cooler seal, wet and dry, air and slurry)	...	71 (160)	240 d	0.003 (0.1) max	...	89
Stainless steels									
304	S30400	...	Carbon black processing; field or plant test; no aeration; rapid agitation. Carbon-black slurry, carbonates, chlorides, sulfates, carbon dioxide and sulfur dioxide from cooling water at pH 7 (bottom of primary cooler)	...	204-482 (400-900)	42 d	0.028 (1.1)	...	89
304	S30400	...	Carbon black processing; field or plant test; slight to moderate aeration; rapid agitation. Carbon black, sulfur, salt and water vapor, oxygen (wet scrubber unit)	...	215 (420)	15 d	0.005 (0.2)	...	89
304	S30400	...	Carbon black processing; field or plant test; strong aeration; rapid agitation. Carbon black, hard water (fresh water 52 salt grains/gal), steam (half immersed)	...	66 (152)	30 d	0.003 (0.1)	Severe pitting	89
304	S30400	...	Carbon black processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry, plus sulfuric acid pH 2 (leaching tank)	...	43 (110)	3 d	0.010 (0.4)	...	89
304	S30400	...	Chemical processing. Activated carbon "SXAC-L" adsorbing acetone, trace methylene chloride	...	...	57 d	0.003 (0.1) max	Crevice attack	89
304	S30400	...	Chemical processing. Activated carbon bed "Norit Sorbonorit III" adsorbing acetone containing trace methylene chloride	...	...	57 d	0.005 (0.2)	Moderate pitting: stress-corrosion cracking	89
304	S30400	...	Chemical processing; field or plant test; strong aeration; slight to moderate agitation. Carbon black loose, entrained combustion gases, water vapor, product occasionally on fire	...	49 (120)	324 d	0.028 (1.1)	Severe pitting	89
304	S30400	...	Chemical processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry and water intermittently, pH 7 approx. (water level of cooler seal, wet and dry, air and slurry)	...	71 (160)	240 d	0.008 (0.3)	Severe pitting: crevice attack	89
304	S30400	...	Petroleum processing; field or plant test; slight to moderate agitation. With carbon over the standard maximum. Plus 80% water (mixer), 20% carbon black paste	...	24 (75)	28 d	0.003 (0.1)	Crevice attack	89
304	S30400	...	Power processing; field or plant test; strong aeration; slight to moderate agitation. Coal (coal chutes)	...	Room	257 d	0.12 (4.7)	...	89
304	S30400	...	Printing; field or plant test; strong aeration; no agitation. With carbon over the standard maximum. Activated carbon bed "Lactol," petroleum solvent, steam, some unknown chloride source	...	Room to 110 (230)	70 d	0.003 (0.1)	Severe pitting: stress-corrosion cracking	89
316	S31600	...	Carbon black processing; field or plant test; no aeration; rapid agitation. Carbon-black slurry, carbonates, chlorides, sulfates, carbon dioxide and sulfur dioxide from cooling water at pH 7 (bottom of primary cooler)	...	204-482 (400-900)	42 d	0.025 (1.0)	...	89
316	S31600	...	Carbon black processing; field or plant test; slight to moderate aeration; rapid agitation. Carbon black, sulfur, salt and water vapor, oxygen (wet scrubber unit)	...	215 (420)	15 d	0.005 (0.2)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Carbon black processing; field or plant test; strong aeration; rapid agitation. Carbon black hard water (fresh water 52 salt grains/gal), steam (half immersed)	...	66 (152)	30 d	0.003 (0.1)	...	89
316	S31600	...	Carbon black processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry, plus sulfuric acid pH 2 (leaching tank)	...	43 (110)	3 d	0.013 (0.5)	...	89
316	S31600	...	Chemical processing. Activated carbon "SXAC-L" adsorbing acetone, trace methylene chloride	...	...	57 d	0.003 (0.1) max	Crevice attack	89
316	S31600	...	Chemical processing. Activated carbon bed "Norit Sorbonorit III" adsorbing acetone containing trace methylene chloride	...	...	57 d	0.003 (0.1)	Moderate pitting: crevice attack	89
316	S31600	...	Chemical processing; field or plant test; strong aeration; slight to moderate agitation. Carbon black loose, entrained combustion gases, water vapor, product occasionally on fire	...	49 (120)	324 d	0.003 (0.1)	Severe pitting	89
316	S31600	...	Chemical processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry and water intermittently, pH 7 approx. (water level of cooler seal, wet and dry, air and slurry)	...	71 (160)	240 d	0.003 (0.1) max	...	89
316	S31600	...	Petroleum processing; field or plant test; slight to moderate agitation. With carbon over the standard maximum. Plus 80% water (mixer), 20% carbon black paste	...	24 (75)	28 d	0.003 (0.1)	...	89
316	S31600	...	Power processing; field or plant test; strong aeration; slight to moderate agitation. Coal (coal chutes)	...	Room	257 d	0.12 (4.6)	...	89
316	S31600	...	Printing; field or plant test; strong aeration; no agitation. Activated carbon bed "Lactol," petroleum solvent, steam, some unknown chloride source	...	Room to 110 (230)	70 d	0.003 (0.1)	Severe pitting: stress-corrosion cracking	89
317	S31700	...	Carbon black processing; field or plant test; no aeration; rapid agitation. Carbon-black slurry, carbonates, chlorides, sulfates, carbon dioxide and sulfur dioxide from cooling water at pH 7 (bottom primary cooler)	...	204-482 (400-900)	42 d	0.018 (0.7)	...	89
317	S31700	...	Carbon black processing; field or plant test; slight to moderate aeration; rapid agitation. Carbon black, sulfur, salt and water vapor, oxygen (wet scrubber unit)	...	215 (420)	15 d	0.003 (0.1)	...	89
317	S31700	...	Carbon black processing; field or plant test; strong aeration; rapid agitation. Carbon black hard water (fresh water 52 salt grains/gal), steam (half immersed)	...	66 (152)	30 d	0.003 (0.1)	...	89
317	S31700	...	Chemical processing. Activated carbon "SXAC-L" adsorbing acetone, trace methylene chloride	...	...	57 d	0.003 (0.1) max	Crevice attack	89
317	S31700	...	Chemical processing. Activated carbon bed "Norit Sorbonorit III" adsorbing acetone containing trace methylene chloride	...	...	57 d	0.003 (0.1)	Maximum depth of pits from incipient to 0.005 in.	89
317	S31700	...	Chemical processing; field or plant test; strong aeration; slight to moderate agitation. Carbon black loose, entrained combustion gases, water vapor, product occasionally on fire	...	49 (120)	324 d	0.003 (0.1) max	Severe pitting	89
AM-363	S36300	...	...	...	Room	...	Resistant	...	120

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	Carbon black processing; field or plant test; strong aeration; rapid agitation. Carbon black hard water (fresh water 52 salt grains/gal), steam (half immersed)	...	66 (152)	30 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Carbon black processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry, plus sulfuric acid pH 2 (leaching tank)	...	43 (110)	3 d	0.033 (1.3)	...	89
Carpenter 20	...	...	Chemical processing. Activated carbon "SXAC-L" adsorbing acetone, trace methylene chloride	...	...	57 d	0.003 (0.1) max	Slight pitting	89
Carpenter 20	...	...	Chemical processing. Activated carbon bed "Norit Sorbonorit III" adsorbing acetone containing trace methylene chloride	...	...	57 d	0.003 (0.1)	Moderate pitting	89
Carpenter 20	...	...	Chemical processing; field or plant test; strong aeration; slight to moderate agitation. Carbon black loose, entrained combustion gases, water vapor, product occasionally on fire	...	49 (120)	324 d	0.003 (0.1)	Moderate pitting	89
Carpenter 20	...	...	Chemical processing; field or plant test; strong aeration; strong agitation. Carbon-black slurry and water intermittently, pH 7 approx. (water level of cooler seal, wet and dry, air and slurry)	...	71 (160)	240 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Printing; field or plant test; strong aeration; no agitation. Activated carbon bed "Lactol," petroleum solvent, steam, some unknown chloride source	...	Room to 100 (230)	70 d	0.003 (0.1) max	Severe pitting	89

Carbon Bisulfide

Also known as carbon disulfide, CS_2, is a toxic, colorless liquid, soluble in water and alcohol, with a boiling point of 46.3 °C. It is used as an organic solvent for oils, fats, rubbers, in paint removers, and in the manufacture of carbon tetrachloride and rayon.

Corrosion Behavior of Various Metals and Alloys in Carbon Bisulfide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon Bisulfide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Carbon Dioxide

Carbon dioxide, CO_2, also known as carbonic anhydride and carbonic acid gas, is a colorless, odorless gas that liquifies at -65 °C (-86 °F) and solidifies in dry ice at -78.2 °C (-107 °F). It is soluble in water, alcohol, and most alkaline solutions. In a relatively slow reaction, carbon dioxide hydrates in water to become carbonic acid and is corrosive. In petroleum production, the velocity of the carbon dioxide gas can increase the corrosion rate to very high levels, with the presence of salts becoming unimportant. Carbon dioxide is used in preparing carbonated beverages, fire extinguishers, dry ice refrigerants, and as a raw material in the production of sodium carbonate and sodium bicarbonate using the Solvay procedure.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy equipment has been used to handle carbon dioxide in the gaseous, liquid, and solid states.

Carbon and Alloy Steels. In oil and gas production, the use of the carbon dioxide injection method has brought about additional corrosion concerns. This method involves the use of carbon dioxide source wells, which can be highly corrosive due to the reaction of carbon dioxide and water, to form carbonic acid. The addition of chloride and hydrogen sulfide increases the acidic activity. The corrosion rates also change with temperature. At 65 °C (150 °F), the lower alloy steels show an increase in weight loss corrosion with increasing carbon dioxide concentration. However, the corrosion resistance improves above 175 °C (350 °F).

Corrosion resistance at a given concentration level improves as the chromium level of the steel increases. Stainless steels exhibit little or no dependence on either the temperature or the carbon dioxide concentration. However, with the addition of chloride at 65 °C (150 °F), higher alloyed steel corrosion rates begin to increase with the increase in carbon dioxide concentration. The corrosion rate of highly alloyed steels increases as the chloride concentration and the temperature increase. The presence of hydrogen sulfide in the carbon dioxide/brine environment increases the corrosion rate of lower alloy and stainless steels. Carbon steel is corrosion resistant to dry carbon dioxide.

Stainless Steels. Martensitic (AISI 410 and 420), austenitic, and duplex stainless steels have been extensively used to handle wet carbon dioxide gas.

Copper. Copper and copper alloys are usually inert to dry carbon dioxide. Corrosion will occur if moisture is present; the rate is determined by the amount of moisture.

Niobium. Niobium is inert in carbon dioxide at 100 °C (212 °F), but reacts with carbon dioxide above 250 °C (480 °F).

Tantalum. Dry carbon dioxide corrodes tantalum at 810 kPa (8 atm) and 500 °C (930 °F). At 1100 °C (2010 °F), carbon dioxide reacts with tantalum to form Ta_2O_5. A gravimetric balance measured the oxidation rates of tantalum at various partial pressures of carbon dioxide at temperatures ranging from 700 to 950 °C (1290 to 1740 °F). The linear oxidation behavior has been explained by the initial absorption of carbon dioxide followed by the formation of a nonprotective surface layer of Ta_2O_5. Both an equilibrium process and a steady-state reaction have been used to describe the absorption phase.

Tin. Carbon dioxide reacts with molten tin to form carbon monoxide and tin oxide.

Titanium. A protective oxide film allows titanium alloys to resist attack by either wet or dry carbon dioxide at temperatures of 150 °C (300 °F) or above.

Zirconium. Zirconium resists attack by carbon dioxide up to 300 to 400 °C (570 to 750 °F).

Corrosion Behavior of Various Metals and Alloys in Carbon Dioxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Carbon and alloy steels									
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	2 h	3.3 (132)	...	24
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	24 h	2.8 (110)	...	24

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	72 h	2.5 (98)	...	24
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	2 h	5.4 (216)	...	24
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	24 h	4.3 (170)	...	24
API N-80 steel	...	...	Aqueous solution plus 1 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	72 h	2.2 (88)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	2 h	1.6 (63)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	24 h	0.4 (17)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	Room	72 h	0.3 (12)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	2 h	4.5 (180)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	24 h	0.6 (26)	...	24
API N-80 steel	...	...	Aqueous solution plus 14 ppt $NaHCO_3$; pressure at 0.83 MPa	...	95 (200)	72 h	0.01 (0.5)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaCl; pressure at 0.83 MPa	...	Room	2 h	3.0 (121)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaCl; pressure at 0.83 MPa	...	Room	24 h	4.4 (175)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaCl; pressure at 0.83 MPa	...	Room	72 h	2.4 (96)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaOH; pressure at 0.83 MPa	...	95 (200)	2 h	25 (1000)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaOH; pressure at 0.83 MPa	...	95 (200)	24 h	8.2 (328)	...	24
API N-80 steel	...	...	Aqueous solution plus 4% NaOH; pressure at 0.83 MPa	...	95 (200)	72 h	1.3 (50)	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	Room	2 h	5 (200)	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	Room	24 h	2.3 (90)	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	Room	72 h	3 (120) min	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	95 (200)	2 h	14 (550)	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	95 (200)	24 h	7.6 (307)	...	24
API N-80 steel	...	...	Aqueous solution; pressure at 0.83 MPa	...	95 (200)	72 h	7.0 (280)	...	24
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Good	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Good	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Dry	...	...	...	0.05 (2) max	...	96
Ampco 8, aluminum bronze	C61300	...	Wet	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Questionable	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93

(Continued)

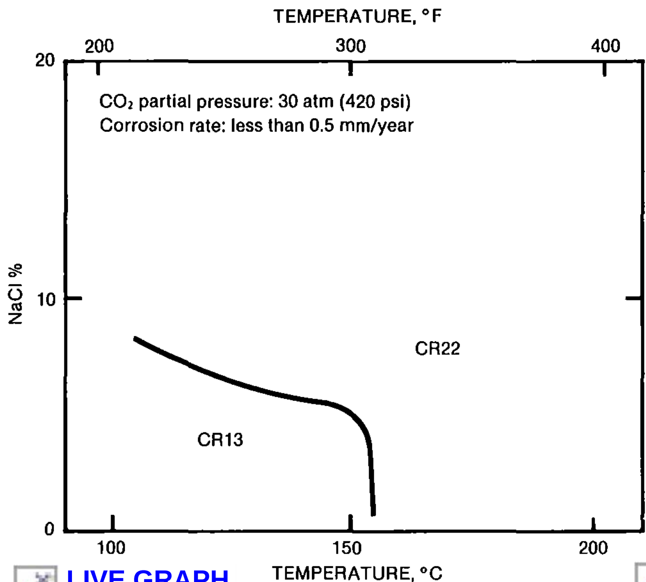
Corrosion Behavior of Various Metals and Alloys in Carbon Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Brass	...	...	Moist	...	...	...	Good	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Questionable	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Questionable	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Good	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Good	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Good	...	93
Miscellaneous									
Magnesium	...	...	Dry	100	Room	...	Resistant	...	119
Platinum	P04995	...	No reductant present	...	1400 (2550)	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Room	...	0.05 (2) max	...	8
Nickel and alloys									
Alloy 825	N08825	...	Plus carbon dioxide and nitrogen, trace chlorine (gaseous mixture)	...	150-200 (302-392)	198 d	0.033 (1.3)	Severe pitting; crevice attack	89
Alloy 825	N08825	...	Rapid agitation. Plus 6% oxygen, 2% carbon monoxide, sulfur dioxide, trace nitrogen	26	40-45 (104-113)	75 d	0.050 (2.0)	Severe pitting	89
Refractory metals and alloys									
Titanium	...	...	...	100	...	...	Resistant	...	90
Stainless steels									
301	S30100	...	Dry	...	Hot	...	Resistant	...	253
301	S30100	...	Moist	...	Hot	...	Resistant	...	253
302	S30200	...	Dry	...	Hot	...	Resistant	...	253
302	S30200	...	Moist	...	Hot	...	Resistant	...	253
303	S30300	...	Dry	...	Hot	...	Resistant	...	253
303	S30300	...	Dry	...	Hot	...	Resistant	...	253
303	S30300	...	Moist	...	Hot	...	Good	...	253
303	S30300	...	Moist	...	Hot	...	Resistant	...	253
304	S30400	...	Dry	...	21 (70)	...	Resistant	...	121
304	S30400	...	Dry	...	Hot	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon Dioxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Food processing; carbonated water, pressure <5 psig	...	...	5 d	Resistant	...	89
304	S30400	...	Moist	...	Hot	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Plus 66.66% water, trace ethanolamine (vapor line of Girdler reactivator)	33.34	113-116 (235-240)	62 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; rapid agitation. Plus 88% nitrogen, condensed water has 40 ppm iron ions, 3 ppm sulfuric and sulfurous, nitric and nitrous acids (pipe, gas steam)	12	43 (110)	36 d	0.003 (0.1) max	...	89
304	S30400	...	Strong aeration; rapid agitation. Gas stream, 2% carbon monoxide, 0.25% sulfur dioxide, some oxygen	10	66 (150)	73 d	0.003 (0.1) max	Slight pitting	89
304	S30400	...	Strong aeration; rapid agitation. With carbon over the standard maximum. Gas stream, 2% carbon monoxide, 0.25% sulfur dioxide, some oxygen	10	66 (150)	73 d	0.003 (0.1) max	Slight pitting	89
304L	S30403	...	Dry	...	Hot	...	Resistant	...	253
304L	S30403	...	Moist	...	Hot	...	Resistant	...	253
304LN	S30453	...	Dry	...	Hot	...	Resistant	...	253
304LN	S30453	...	Moist	...	Hot	...	Resistant	...	253
316	S31600	...	Dry	...	21 (70)	...	Resistant	...	121
316	S31600	...	Dry	...	Hot	...	Resistant	...	253
316	S31600	...	Moist	...	Hot	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Plus 66.66% water, trace ethanolamine (vapor line of Girdler reactivator)	33.34	113-116 (235-240)	62 d	0.050 (2.0)	...	89
316	S31600	...	No aeration; rapid agitation. Plus 88% nitrogen, condensed water has 40 ppm iron ions, 10 ppm sulfuric and sulfurous acids, 3 ppm nitric and nitrous acids (pipe, gas steam)	12	43 (110)	36 d	0.003 (0.1) max	...	89
316	S31600	...	Rapid agitation. Plus carbon dioxide and nitrogen, trace chlorine (gaseous mixture)	...	150-200 (302-392)	198 d	0.006 (2.2)	Severe pitting; crevice attack	89
316	S31600	...	Strong aeration; rapid agitation. Gas stream, 2% carbon monoxide, 0.25% sulfur dioxide, some oxygen.	10	66 (150)	73 d	0.003 (0.1) max	...	89
316	S31600	...	Water purification; rapid agitation. Plus 6% oxygen, 2% carbon monoxide, sulfur dioxide, trace nitrogen	26	40-45 (104-113)	75 d	0.030 (1.2)	Severe pitting	89
316F	S31620	...	Dry	...	Hot	...	Resistant	...	253
316F	S31620	...	Moist	...	Hot	...	Resistant	...	253
316L	S31603	...	Dry	...	Hot	...	Resistant	...	253
316L	S31603	...	Moist	...	Hot	...	Resistant	...	253
316LN	S31653	...	Dry	...	Hot	...	Resistant	...	253
316LN	S31653	...	Moist	...	Hot	...	Resistant	...	253
316Ti	S31635	...	Dry	...	Hot	...	Resistant	...	253
316Ti	S31635	...	Moist	...	Hot	...	Resistant	...	253
317	S31700	...	No aeration; rapid agitation. Plus 66.66% water, trace ethanolamine (vapor line of Girdler reactivator)	33.34	113-116 (235-240)	62 d	0.003 (0.1)	...	89
317	S31700	...	No aeration; rapid agitation. Plus 88% nitrogen, condensed water has 40 ppm iron ions, 10 ppm sulfuric and sulfurous acids, 3 ppm nitric and nitrous acids (pipe, gas steam)	12	43 (110)	36 d	0.003 (0.1) max	...	89
317	S31700	...	Rapid agitation. Plus carbon dioxide and nitrogen, trace chlorine (gaseous mixture)	...	150-200 (302-392)	198 d	0.050 (2.0)	Severe pitting; crevice attack	89
317L	S31703	...	Dry	...	Hot	...	Resistant	...	253



LIVE GRAPH
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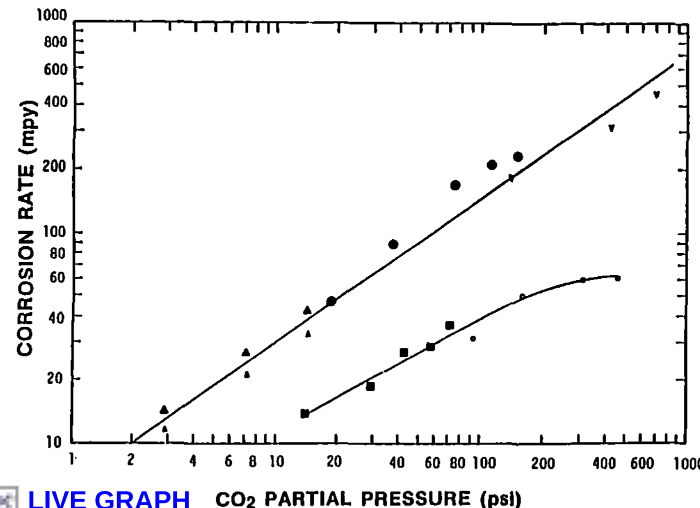
Stainless steel. Relative corrosion resistance of 13% chromium stainless steel and duplex stainless steel (Cr 22) in carbon dioxide as a function of temperature and sodium chloride content. Source: Nippon Kokan K.K.



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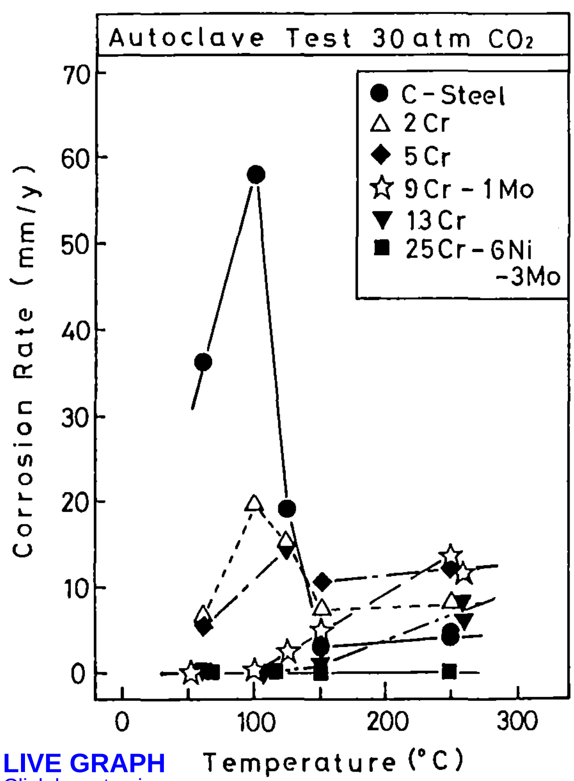
Steel. Corrosion rate of steel as a function of carbon dioxide partial pressure. Source: D.W. De Berry and W.S. Clark, "Corrosion Due to Use of CO_2 for Enhanced Oil Recovery," U.S. Department of Energy, DOE/MC/08442-T1, 1979.



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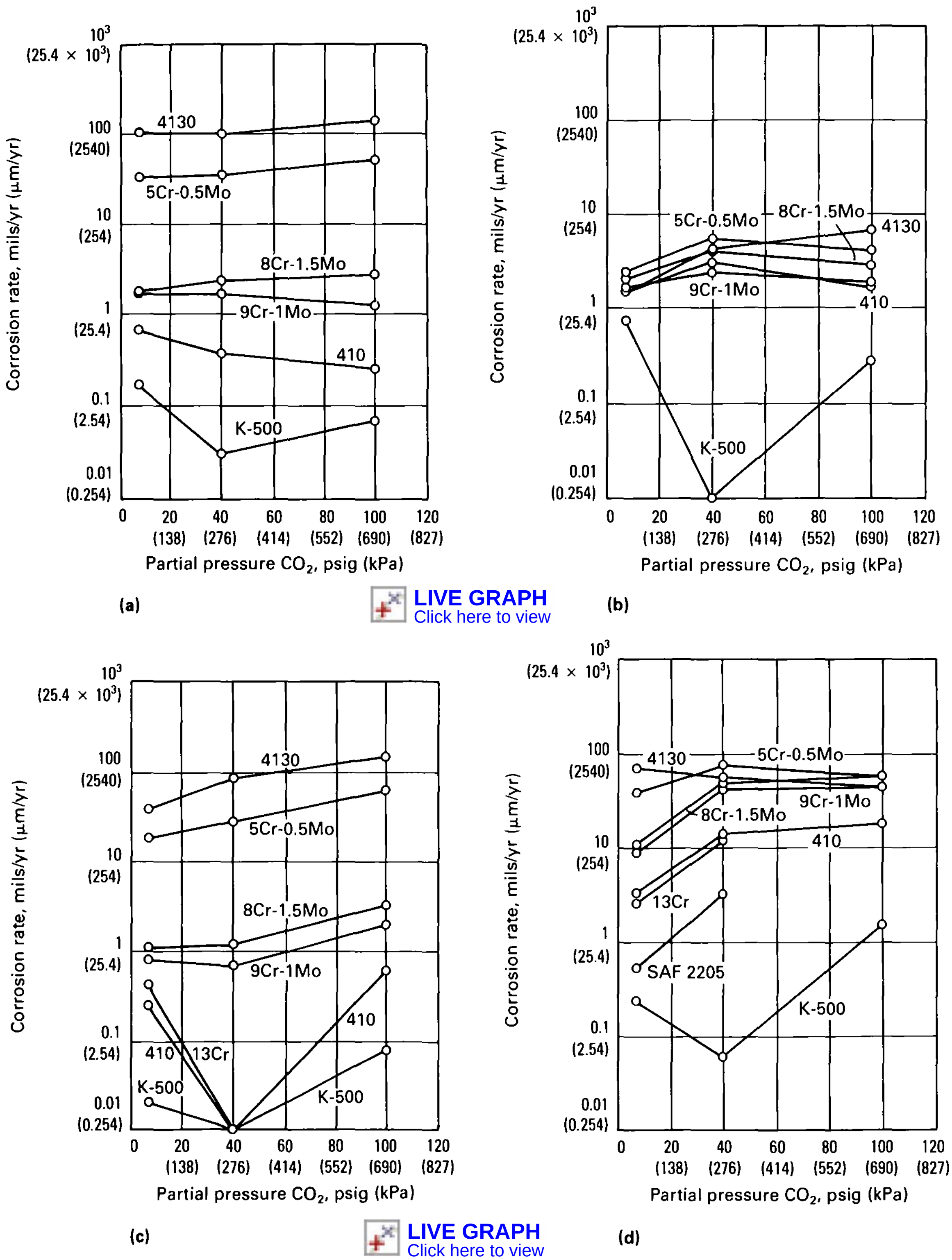
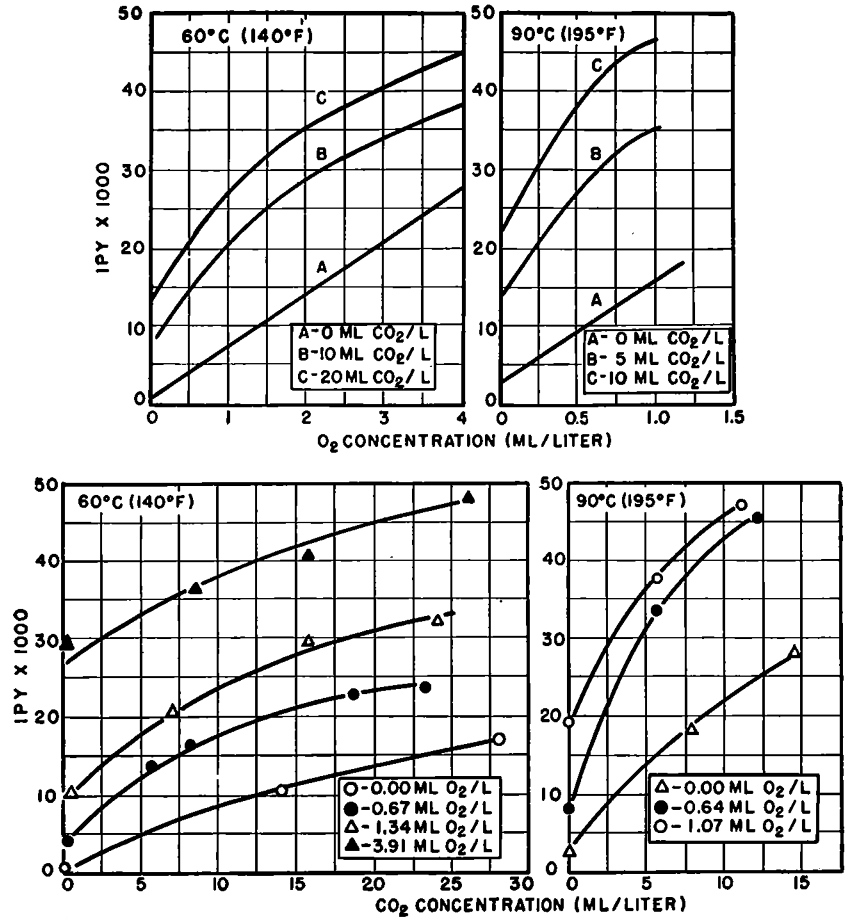
Steels. Corrosion of chromium steels in high-pressure wet carbon dioxide as a function of temperature. Source: A. Ikeda, S. Mukai, and M. Ueda, CO_2 Corrosion Behavior of Carbon and Chromium Steels, *Sumimo Search*, *31*, 91-102, 1985.



Alloy steels. Effect of partial pressure of carbon dioxide on the corrosion rates of various alloy steels. (a) 0% chlorides at 65 °C (150 °F). (b) 0% chlorides at 175 °C (350 °F). (c) 15.2% chlorides at 65 °C (150 °F). (d) 15.2% chlorides at 175 °C (350 °F). Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 536.



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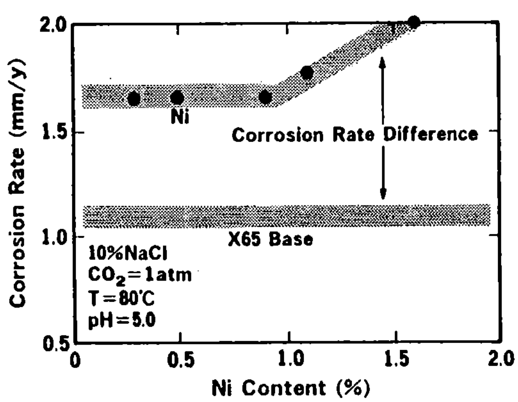
Carbon steel. Corrosion of mild steel (0.15% carbon) as a function of dissolved carbon dioxide and oxygen concentration during a 5-h test; velocity, 45 cm (0.025 ft) per min; specimen size, 6.3 x 2.5 x 0.318 cm (2.5 x 1 x 1/8 in.). Source: H.H. Uhlig, Iron and Steel, in *The Corrosion Handbook*, H.H. Uhlig, Ed., John Wiley & Sons, New York, 1948, 128.



Linepipe steel. The effect of Ni content on the corrosion rate of linepipe steel. Top curve is for the weld metal; bottom curve is for the base metal. Ref. 278

LIVE GRAPH
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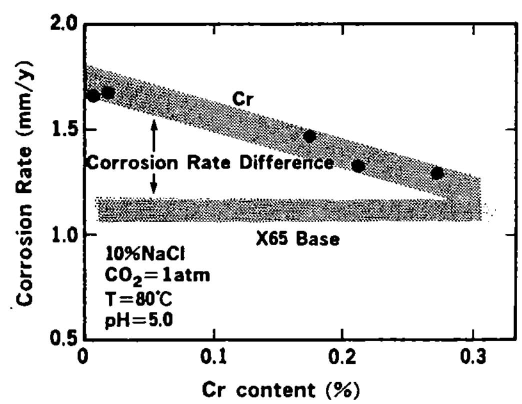

Linepipe steel. The effect of Cr content on the corrosion rate of linepipe steel. Top curve is for the weld metal; bottom curve is for the base metal. Ref. 278

LIVE GRAPH
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Carbon Monoxide

Carbon monoxide, CO, is a colorless, odorless, toxic gas. It is soluble in alcohol and cuprix chloride solutions, but insoluble in water. Carbon monoxide is formed by the incomplete oxidation of carbon. It is found in mines and car exhaust. Carbon monoxide is used in metallurgy as a reducing agent in smelting operations, in the production of carbonyls for the separation of various metals, as an ingredient in the synthesis of phosgene, and as an intermediate in the production of methanol.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Copper and its alloys are inert in dry carbon monoxide. However, corrosion does occur in the presence of moisture; the rate of attack depends on the amount of moisture available. High-pressure equipment made of alloy steels are often lined with copper or copper alloys to protect the alloy steel from carbon monoxide attack.

Niobium. Niobium reacts with carbon monoxide at temperatures above 250 °C (480 °F).

Silver. Silver is not affected by carbon monoxide up to 300 °C (570 °F).

Tantalum. Tantalum reacts with carbon monoxide at 1100 °C (2010 °F) to form tantalum oxide, TaO, which converts to tantalum pentoxide, Ta_2O_5, in the presence of oxygen.

Titanium. Titanium alloys have an oxide film that protects them from attack by either wet or dry carbon monoxide at temperatures up to 150 °C (300 °F).

Zirconium. Zirconium is stable in carbon monoxide at temperatures up to 300 to 400 °C (570 to 750 °F).

Corrosion Behavior of Various Metals and Alloys in Carbon Monoxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Gas	...	500 932 max	...	Resistant	...	92
Aluminum alloys	...	...	Gas	...	500 932 max	...	Resistant	...	92
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	No reductant present	...	1400 (2550)	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	300 (570)	...	0.05 (2) max	...	8
Stainless steels									
304	S30400	...	Chemical processing. Carbon monoxide, high pressure	...	200 (392)	...	Good	...	89

Carbon Tetrachloride

Carbon tetrachloride, CCl_4, also known as tetrachloromethane, perchloro methane, and benzinoform, is a colorless liquid with a boiling point of 77 °C (170 °F). It is used as a solvent for lacquers, resin, and rubbers, and as a dry cleaning agent.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests showed that carbon tetrachloride at ambient temperature did not attack aluminum alloys 3003, 5052, and 5154, but was very corrosive at the boiling point, 77 °C (170 °F). The reaction, evidently electrochemical, produces aluminum chloride, which acts as an accelerator and hexachloroethane. The reaction rate is very depend-

ent on temperature and decreases as the temperature drops from boiling to 50 °C (122 °F). It increases when superheated. The reaction rate increased at lower temperatures when carbon disulfide, water, or oxygen were present, but the same substances decreased the reaction rate at higher temperatures. Stabilizers help control the rate. Aluminum powder that has been in contact with carbon tetrachloride should not be used as a milling medium for comminuting aluminum.

Corrosion Behavior of Various Metals and Alloys in Carbon Tetrachloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Wet	...	20 (68)	...	Resistant	...	92
Aluminum alloys	...	...	Wet	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Good	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Good	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Poor	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Good	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Poor	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Poor	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Poor	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Poor	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Good	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Good	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Good	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carbon Tetrachloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Platinum	P04995	...	Dry and wet	...	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	Dry and wet	...	Boiling	...	0.05 (2) max	...	10
Refractory metals and alloys									
Titanium	...	...	...	99	Boiling	...	0.003 (0.12)	...	20
Titanium	...	...	...	100	Boiling	...	0.003 (0.12)	...	20
Titanium	...	...	...	99	Boiling	...	0.005 (0.2)	...	90
Titanium	...	...	...	Liquid	Boiling	...	Resistant	...	90
Titanium	...	...	...	Vapor	Boiling	...	Resistant	...	90
Titanium	...	...	Plus 50% H_2O	50	25 (77)	...	0.005 (0.2)	...	90
Zr702	R60702	...	...	0-100	Room to 100	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	20 (68)	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing (distillation); field or pilot plant test; no aeration; rapid agitation. With carbon over the standard maximum. Plus 75-95% sulfur chlorides (sulfur mono- and dichloride, thiocarbonyl chloride, etc.) (liquid line)	5-25	52-54 (125-130)	35.5 d	0.003 (0.1)	...	89
304	S30400	...	Chemical processing (rectification); field or pilot plant test; no aeration; rapid agitation. Crude carbon tetrachloride (column)	...	80 (176)	133 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 12% water, 0.4% chlorine, 0.1% hydrochloric acid (vapors)	87.5	60-85 (140-185)	3 d	39 (1570)	Severe pitting	89
304	S30400	...	Dry cleaning (distillation); field or pilot plant test; no aeration; rapid agitation. With carbon over the standard maximum. "Kolene" solvent, 10% benzene (bottom of still)	90	142 (287)	38 d	0.035 (1.4)	Slight pitting	89
304	S30400	...	Dry cleaning (distillation); field or pilot plant test; no aeration; rapid agitation. "Kolene" solvent, 10% benzene (bottom of still)	90	142 (287)	38 d	0.035 (1.4)	Slight pitting	89
304	S30400	...	Dry cleaning; field or pilot plant test; no aeration; no agitation. "Kolene" solvent, 10% benzene	90	Room	40 d	0.003 (0.1) max	...	89
304L	S30403	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Next Page

Corrosion Behavior of Various Metals and Alloys in Carbon Tetrachloride (Continued)

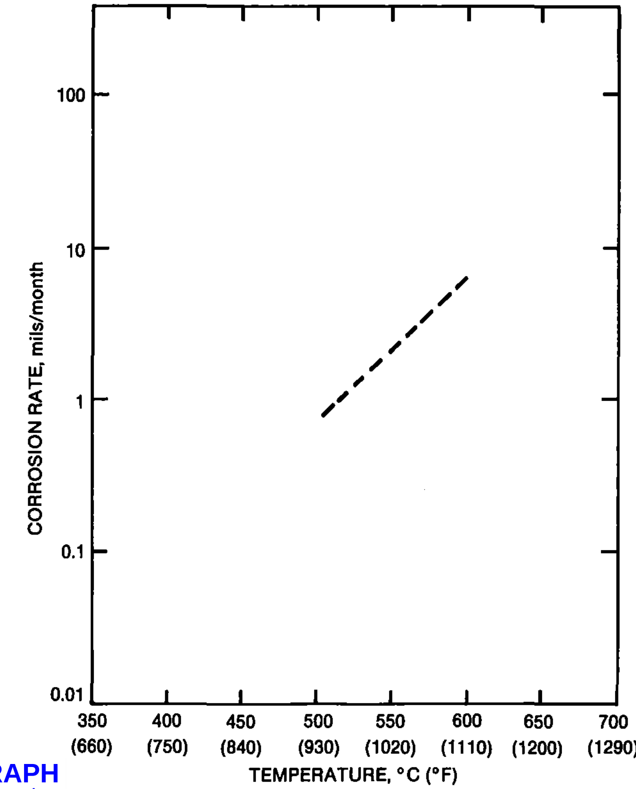
Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing (distillation); field or pilot plant test; no aeration; rapid agitation. Plus 75-95% sulfur chlorides (sulfur mono- and dichloride, thiocarbonyl chloride, etc.) (liquid line)	5-25	52-54 (125-130)	35.5 d	(0.003) 0.1	...	89
316	S31600	...	Chemical processing (rectification); field or pilot plant test; no aeration; rapid agitation. Crude carbon tetrachloride (column)	...	80 (176)	133 d	0.003 (0.1) max	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 12% water, 0.4% chlorine, 0.1% hydrochloric acid (vapors)	87.5	60-85 (140-185)	3 d	32 (1260)	Severe pitting	89
316	S31600	...	Dry cleaning (distillation); field or pilot plant test; no aeration; rapid agitation. "Kolene" solvent, 10% benzene (bottom of still)	90	142 (287)	38 d	0.020 (0.8)	Slight pitting	89
316	S31600	...	Dry cleaning; field or pilot plant test; no aeration; no agitation. "Kolene" solvent, 10% benzene	90	Room	40 d	0.003 (0.1) max	...	89
316F	S31620	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	20 (68)	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	20 (68)	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	20 (68)	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	20 (68)	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Questionable	...	121
410	S41000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	Vapors refluxed	...	Room	...	Good	...	121
416	S41600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Previous Page

Corrosion Behavior of Various Metals and Alloys in Carbon Tetrachloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	...	Anhydrous	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253



LIVE GRAPH
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Hastelloy C. Corrosion of Hastelloy alloy C by carbon tetrachloride vapor plus air after 70-h exposure. Source: W.Z. Friend, *Corrosion of Nickel and Nickel-base Alloys*, John Wiley & Sons, New York, 1980, 362.

Carbonic Acid

Carbonic acid, H_2CO_3, exists in solution only. It is prepared by the combination of carbon dioxide and water. For additional information, please see Carbon Dioxide.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy equipment has been used successfully to handle carbonated beverages.

Titanium. Titanium exhibits an almost nil corrosion rate for all concentrations of carbonic acid well beyond its boiling point.

Corrosion Behavior of Various Metals and Alloys in Carbonic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	1.25 (50) min	...	95
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	4
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	4
Refractory metals and alloys									
Zr702	R60702	...	...	Saturated	100 (212)	...	0.13 (5) max	...	15
Stainless steels									
304	S30400	...	...	...	21 (70)	...	Good	...	121
316	S31600	...	...	...	21 (70)	...	Good	...	121
430	S43000	...	...	...	21 (70)	...	Good	...	121
410	S41000	...	...	...	21 (70)	...	Good	...	121

Carnallite

This mineral is a product of evaporation of saline deposits rich in potash content, as a hydrated chloride of potassium and magnesium, $KMgCl_3{\cdot}6H_2O$. It crystallizes in the orthorhombic system usually as massive, granular aggregates. Luster greasy, with indistinct cleavage and conchoidal fracture. Color grades from colorless to white, into reddish from included hematite scales. Transparent to translucent with bitter taste, deliquesces readily in moist environment.

Corrosion Behavior of Various Metals and Alloys in Carnallite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Good	Pitting	253
302	S30200	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
304	S30400	...	...	...	Boiling	...	Good	Pitting	253
304L	S30403	...	...	...	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	...	...	Boiling	...	Good	Pitting	253
316F	S31620	...	...	...	Boiling	...	Good	Pitting	253
316L	S31603	...	...	...	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Good	Pitting	253
317L	S31703	...	...	...	Boiling	...	Good	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Good	Pitting	253
321	S32100	...	...	...	Boiling	...	Good	Pitting	253
329	S32900	...	...	...	Boiling	...	Good	Pitting	253
347	S34700	...	...	...	Boiling	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Carnallite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	...	20 (68)	...	Questionable	Pitting	253
403	S40300	...	...	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	...	Boiling	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Questionable	Pitting	253
430	S43000	...	...	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	...	Boiling	...	Good	Pitting	253
F51	S31803	...	...	...	Boiling	...	Good	Pitting	253

Cellulose Acetate

Cellulose acetate is the general name for the acetic acid esters of cellulose, cellulose pentaacetate, $C_6H_5(OOCCH_3)_5$, cellulose tetraacetate, $C_6H_6(OOCCH_3)_4$, and cellulose triacetate, $C_6H_7O_2(OOCCH_3)_3$. Cellulose acetate is a tough, flexible, slow-burning and long-lasting material used in the production of plastic film for food packaging, magnetic tape, and movie film.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Cellulose acetate has been prepared and stored successfully in aluminum alloy equipment.

Corrosion Behavior of Various Metals and Alloys in Cellulose Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	0.05 (2) max	...	95

Cesium Hydroxide

Cesium hydroxide, CsOH, also known as cesium hydrate, is a colorless to yellowish deliquescent solid. It is formed by the vigorous reaction of cesium and water. Cesium hydroxide is the strongest of the alkali metal hydroxides with the lowest lattice energy. It has a melting point of 272.3 °C (522 °C) and is soluble in water. Cesium hydroxide is used as an electrolyte in alkaline batteries at subzero temperatures.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Silver. Silver is not attacked by cesium hydroxide at temperatures slightly below 500 °C (930 °F).

Corrosion Behavior of Various Metals and Alloys in Cesium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	All	500 (930)	...	0.05 (2) max	...	9

Chloric Acid

Chloric acid, $HClO_3 \cdot 7H_2O$, is a toxic compound very soluble in water which decomposes at 40 °C. Used as a catalyst, it ignites organic matter on contact.

Corrosion Behavior of Various Metals and Alloys in Chloric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	...	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	...	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	...	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	...	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Poor	Pitting	253

Chlorides

All metallic chlorides, except silver chloride and mercurous chloride, are soluble in water. Lead chloride, cuprous chloride, and thallium chloride are only slightly soluble in water. Alkali chlorides are more volatile than the corresponding alkali oxides, nitrates, or sulfates. Metallic chlorides melt when heated and volatilize or decompose. For example, sodium chloride melts at 804 °C (1480 °F), magnesium chloride crystals decompose to yield magnesium oxide residue and hydrogen chloride, and cupric chloride yields cuprous chloride and chlorine. Sodium, calcium, strontium, and barium metals are produced by electrolyzing the molten metallic chloride.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Chlorides are generally more aggressive to stainless steels because of the ability of the chloride ion to penetrate the passive film and cause pitting. Pitting is promoted in aerated or mildly acidic oxidizing solutions. Temperature and chloride concentration affect the degree of pitting and the stress-corrosion cracking. At ambient temperature, chloride pitting of 18Cr-8Ni stainless steel may occur, but stress-corrosion cracking is unlikely. At about 65 °C (150 °F) or above, the stress-corrosion cracking of austenitic grades must be considered. Chloride stress-corrosion cracking may be avoided by use of either ferritic grades of stainless steel with a lower nickel content such as 18Cr-2Mo, or duplex alloys such as 7-Mo PLUS, alloy 2205, and Ferralium 255 in elevated temperature chloride environments.

Crevice corrosion of stainless steels in Cl containing waters is dependent on a number of interrelated factors. Higher Cl levels in bulk solutions enable the occurrence of attack for a broader range of crevice geometries. Because chlorides concentrate in crevices, even low levels in bulk environments can lead to corrosion for some susceptible stainless steels.

The limited corrosion resistance of sintered stainless steels, particularly in a chloride environment, is commonly thought to derive from the presence of residual pores that give rise to crevice corrosion as a result of oxygen depletion within the pores. There is evidence, however, that factors other than porosity often determine corrosion life. For example, despite similar pore volumes, sizes, and shapes, type 316L stainless steel parts prepared from various powder lots and sintered under varying conditions had corrosion resistances in 5% aqueous sodium chloride solution that varied between 5 and 500 h for a specified degree of corrosion. Furthermore, a comparison of wrought and sintered (85% of theoretical density) type 316L for susceptibility to crevice corrosion in 10% ferric chloride showed that the wrought part was even more severely attacked than the porous P/M part. Lastly, surface analyses of water-atomized stainless steel powders showed the presence of large amounts of oxidized silicon concurrent with a severe depletion of chromium. The surface composition of a sintered part depended on its sintering conditions.

The factors of critical importance for the corrosion resistance of sintered stainless steels include control of iron contamination, carbon, nitrogen, oxygen, and sintered part density. Also, the precautions necessary for maximizing corrosion resistance differ with the sintering atmosphere.

Copper. Copper alloys under cyclic stress have shorter service in lives in chloride solutions than in air. Anodically polarizing C26000 and C44300 alloys lowered their fracture stresses in sodium chloride solutions as measured in slow strain experiments.

Magnesium. Chloride solutions are corrosive, because chlorides, even in small amounts, break down the protective film on magnesium.

Amorphous Metals. The stress-corrosion cracking behavior of glassy Fe-Cr-Ni-P-C alloy systems in acidic chloride solutions was investigated with constant extension rate tensile tests. Hydrogen embrittlement occurred at cathodic polarizations up to 300 mV relative to the corrosion potential. In the passive potential region, no cracking occurred in neutral sodium chloride solutions and in acidic solutions at low chloride ion concentrations. Fracture stress decreased only when the specimens were strained in strong acidic solutions containing the chloride ion, and this phenomenon was also attributed to hydrogen embrittlement.

The resistance of Fe-Ni-Cr-P-B glassy alloy filaments to crevice corrosion in acidic solutions containing the chloride ion was attributed to its strong tendency to passivate, which in turn stifled propagation, even under the aggressive conditions of low pH, low dissolved oxygen concentration, and oxidizing potential that prevail within crevices. This resistance to crevice corrosion could be expected to extend to other glassy transition metal-metalloid compositions containing both a film former and phosphorus.

Glassy nickel-phosphorus is another alloy system that has been recently investigated and that appears to resist chloride-induced corrosion. The potentiodynamic polarization curves of both chloride-containing and chloride-free electrolytes are virtually identical. A form of chemical passivity has been proposed to explain the corrosive behavior. Passivation in this system is due to the formation of an ionic barrier layer, not the classic passive oxide film. This barrier layer consists of the hypophosphite ion adsorbed on the nickel-phosphorus surface, which may then be hydrogen bonded to an outer layer of water molecules. This barrier inhibits the transport of water to the surface and thus prevents hydration of nickel, which is the first step in the nickel dissolution process.

Tungsten-iron and titanium-copper alloys prepared by high-rate sputter deposition resisted pitting corrosion up to 2.5 V (SCE) in chloride solutions of pH 1 and 7.

Beryllium. Chloride ions from sources other than tap water can also lead to the pitting attack of beryllium in aqueous baths. Chloride ions may be provided by chlorinated solvents used to clean oils and greases when the solvent is carried into the cleaning bath by an arsenic-machined surface and from plastic piping used in chemical cleaning facilities to avoid metallic contamination.

Nickel. The nickel-chromium-molybdenum alloys, for example alloys C-276, 625, ALLCORR, and C-22, exhibit excellent resistance to pitting in oxidizing chloride media. Pitting resistance is enhanced with the presence of chromium and molybdenum. Nickel alloys are used in pulp and paper mills where conditions are the most corrosive. Alloy 600 has proved to be one of the most resistant alloys to high-temperature chloride salt attack. In fact, alloy 600 along with alloy 800 have been used for over 25 years for digester liquor heater tubing because their high nickel content provides excellent resistance to chloride stress-corrosion cracking. Alloys 601, 617, 690, RA330, and 825 also provide useful resistance.

Tantalum. Over the temperature range commonly used in solution processes, tantalum is inert to phosphorus chlorides.

Tin. The presence of chloride compounds in the paper used for labels and in the materials used in shipping containers may create a serious corrosion problem in tinplate cans during storage. The resistance of tin-silver alloys to chloride attack is considerably better than the resistance of sterling silver. Less discolorization occurred in tin-silver alloys upon heating in air.

Titanium. Titanium alloys generally exhibit superior resistance to crevice corrosion as compared to stainless steel and nickel-base alloys. However, the susceptibility of titanium alloys to crevice corrosion in hot concentrated chloride increases significantly as temperatures increase and pH decreases. Crevice attack of titanium alloys will generally not occur below 70 °C (160 °F) regardless of solution pH or chloride concentration, or when solution pH exceeds 10 regardless of temperature.

Titanium alloy grade 12 provides the most crevice corrosion resistance to hot low-pH salt solutions such as brine with pH between 3 and 11 and at temperatures as high as 300 °C (570 °F). Extensive tests of the crevice corrosion resistance of grade 12 titanium were conducted in concentrated, near-neutral sodium chloride, a mixture of sodium and magnesium chlorides, and ammonium chloride brines at high temperatures. Studies were conducted to assess this alloy for potential application in hypersaline geothermal brine, high-level nuclear waste storage, oil refineries, and salt evaporator brine heaters. In all cases, crevice testing involving Teflon gasket-to-metal and metal-to-metal crevices for extended periods revealed no evidence of significant attack to temperatures as high as 250 °C (480 °F). In saturated ammonium chloride solution, no gasket-to-metal or under-salt-deposit attack was noted to 177 °C (350 °F) and at pH 3 to 7. Similar performance is noted for grade 7 titanium under these conditions.

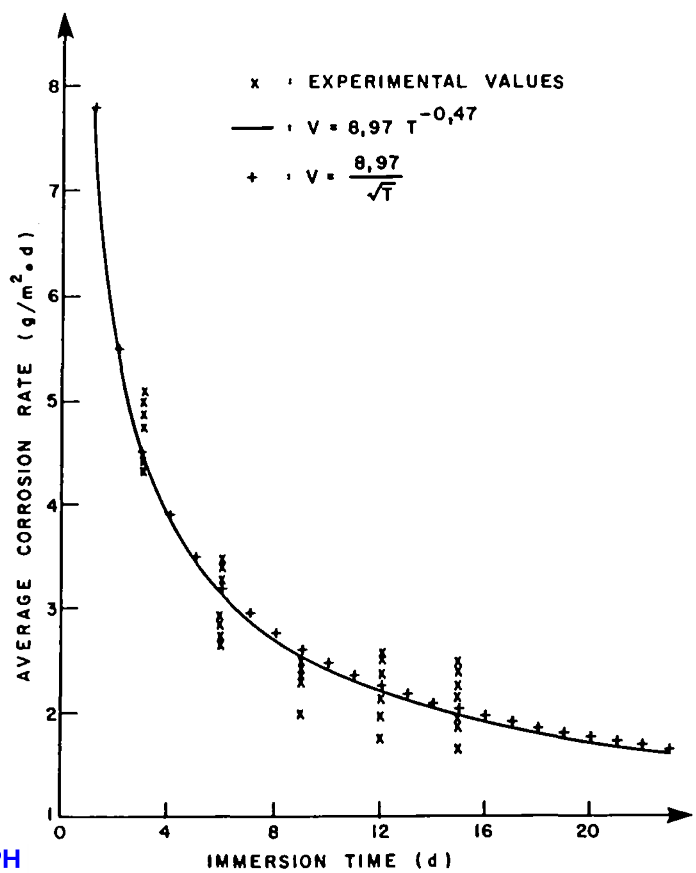
It should be cautioned that deviations from normal crevice corrosion guidelines can be expected in certain acid salts, which when highly con-

centrated may hydrolyze to form hydrogen chloride at high temperatures. These salts include magnesium, calcium, zinc, and aluminum chlorides. Titanium alloy grade 7 is generally the most resistant in these situations. Teflon gasket-to-metal crevices of various high-strength titanium alloys were also tested in hot sodium chloride brines. Relative alloy crevice corrosion resistance generally parallels alloy resistance in reducing acid media. Titanium alloys containing at least 4 wt% molybdenum exhibit significantly increased crevice corrosion in high-temperature sodium chloride media down to relatively low pH values. Increasing the molybdenum content aided the crevice corrosion resistance, as evidenced in Teflon gasket-to-metal tests performed on Ti-3-8-6-4-4 alloy under conditions simulating those of a deep oil well (downhole). At 300 °C (570 °F) in a pH 3 solution prepared with 250 g/L sodium chloride and 1 g/L sulfur and a 103-kPa (15-psi) hydrogen sulfide, titanium alloy Ti-3-8-6-4-4 showed no susceptibility to crevice attack and revealed superior resistance to grade 12 titanium.

The crevice corrosion resistance in hot sodium chloride brines of grade 9 titanium appears to be essentially the same as that for unalloyed titanium. The increased aluminum content in grade 5 titanium alloy, however, slightly reduces the crevice corrosion resistance in comparison to unalloyed grades. Studies of the effect of chloride concentration on the initiation of crevice corrosion in unalloyed titanium indicate that 0.01% chloride ion at 90 °C (195 °F) and 0.10% chloride ion at 70 °C (160 °F) may be threshold conditions for crevice attack in aerated pH 3 to 5 solutions given tight Teflon gasket-to-metal crevices. Tests indicate that crevice tightness and type of gasket are critical to crevice corrosion. Teflon gasket-to-metal crevices are generally more susceptible to crack initiation than silicone rubber, neoprene rubber, asbestos and polyvinyl chloride (PVC) gasket-to-metal crevices. Sealants containing chloride salts may significantly increase susceptibility to crevice attack. Metal-to-metal crevices are generally the least susceptible to attack. The addition of impressed anodic potentials or dissolved oxidizing species can lead to shorter incubation time and increased crevice attack in sodium chloride brines.

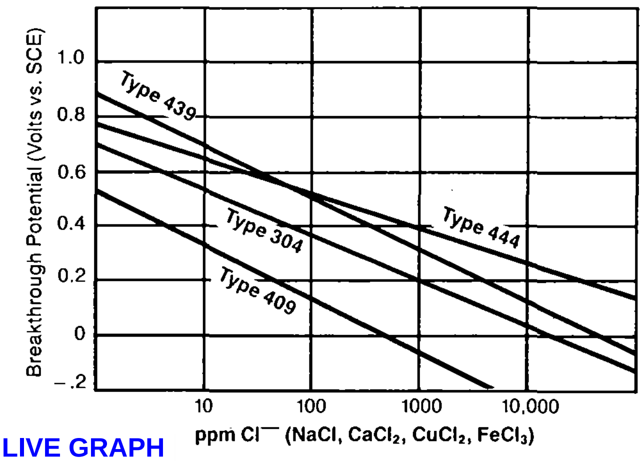
Zinc. Chlorides have a corrosive action on zinc, because water-soluble and hygroscopic salts are formed.

Zirconium. Zirconium is not subject to crevice attack or pitting corrosion in low-pH chloride solutions or chlorine gas.

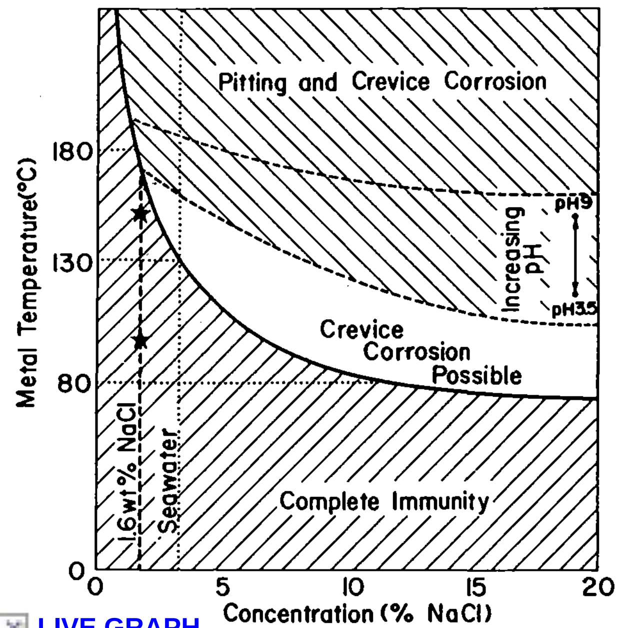


LIVE GRAPH
Click here to view

Cast iron. Average corrosion rate of cast iron as a function of immersion time and in the presence of chlorides and nitrates. (Cl^-) = 157 mg/L; (NO_3^-) = 199.0 mg/L. Source: D.L. Piron and R. Desjardins, "Corrosion Rate of Cast Iron and Copper Pipe by Drinking Water," in *Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods* (STP 908), G.C. Moran and P. Labine, Ed., ASTM, Philadelphia, 1986, 364.



Stainless steels. Effect of chloride concentration on the breakthrough potentials of stainless steels at room temperature. Source: Allegheny Ludlum Corporation, 1985.



Unalloyed titanium. Effect of temperature, chloride concentration, and pH on the localized corrosion of unalloyed titanium. Data on crevice corrosion of grade 2 titanium in 1.6 wt% sodium chloride are included for comparison. Source: P. McKay and D.B. Mitton, "An Electrochemical Investigation of Localized Corrosion on Titanium in Chloride Environments," *Corrosion*, Vol 41, Jan 1985, 61.

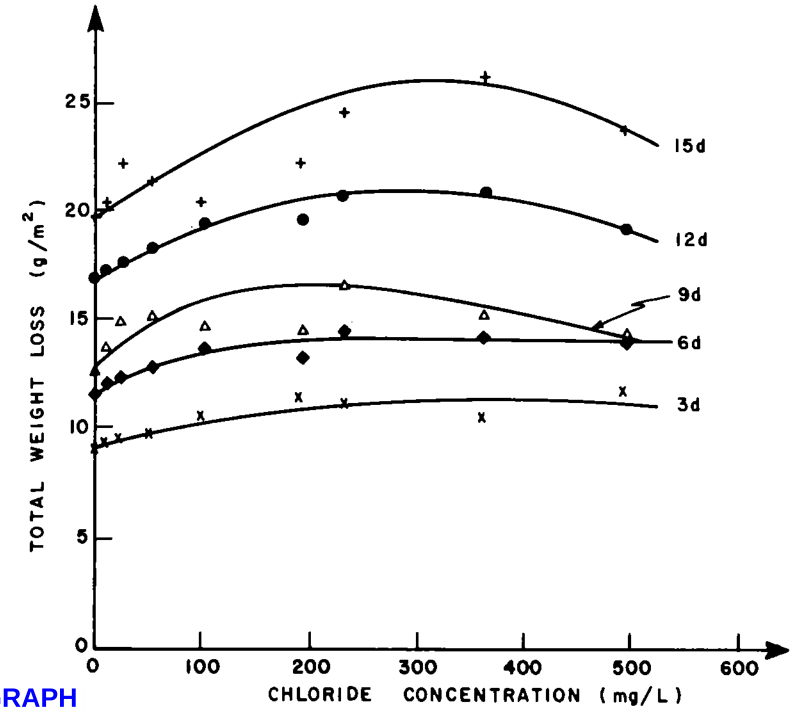
How Various Alloys Rate in Tests in Different Types of Chloride Solutions(a)

Successful alloy tests in chloride solutions

Chloride solution	Carbon steel	Duplex 255 SS*	Ferritic 26-1 SS	Alloy 20 (% Ni >30) 2-3% Mo	Alloy 20 (% Ni >30) 6-9% Mo	Alloy C-276	Titanium Grade 2
Alkaline	Seawater pH = 8 50°C	Seawater pH = 8 50°C	26% NaCl + Na_2CO_3 pH = 11 boiling	Seawater pH = 8 NR† at 25°C‡	Sat'd. NaCl pH = 8.5-10 120°C	Sat'd. NaCl pH = 8.5-10 120°C	Seawater pH = 8 boiling
Neutral pH	22% NaCl 25°C	26% NaCl 200°C	2/% NaCl 25°C	No data	26% NaCl 200°C	Sat'd. NaCl 125°C	26% NaCl 113°C
Acidic	NR†	4% NaCl + 280 ppm Fe^{+3} pH = 2 35°C	6% $FeCl_3$ pH = 1 25°C	4% NaCl + 280 ppm Fe^{+3} pH = 2 15°C	4% NaCl + 280 ppm Fe^{+3} pH = 2 25°C	40% $MgCl_2$ pH = 0.5-1.0 boiling	20% $MgCl_2$ 100°C
Oxidizing	NR†	6% $FeCl_3$ 25°C	10% $FeCl_3$ 38°C	6% $FeCl_3$ Below –5°C	4% NaCl + 280 ppm Fe^{+3} pH = 2 25°C	15% $FeCl_3$ 25°C	40% $FeCl_3$ boiling
Hypochlorite	NR†	No data	5.25% NaOCl 70°C	NR†	10% NaOCl +2% NaOH 30°C	10% NaOCl 25°C	16% NaOCl 25°C

*SS is stainless steel.
†NR is not recommended.
‡Alloy 20Cb-3 pits in seawater at 25°C.

(a) Results of short-term (1 to 10 day) tests. Long-term results may be different.
Source: G.N. Kirby, Selecting Alloys for Chloride Service, *Chemical Engineering, 92*, Feb 1985, p 82.



LIVE GRAPH
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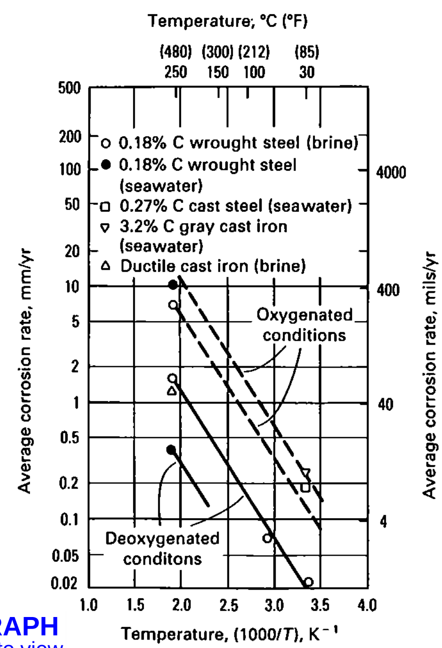
Cast iron. Cumulative weight loss of cast iron as a function of chloride concentration and immersion time. Source: D.L. Piron and R. Desjardins, "Corrosion Rate of Cast Iron and Copper Pipe by Drinking Water," in *Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods* (STP 908), G.C. Moran and P. Labine, Ed., ASTM, Philadelphia, 1986, 369.



LIVE GRAPH
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Cast iron. The effect of temperature on the general corrosion rate of cast iron and steel in chloride solutions. Test duration: 2 to 8 weeks. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 978.

Chlorine

Chlorine (Cl) melts at –101 °C and boils at –34.1 °C. Chlorine gas is about 2½ times heavier than air and is poisonous and irritating to the eyes and throat. Chlorine is used in the manufacture of PVC, solvents, insecticides, and many non-chlorine-containing compounds. It is also used in bleaching of paper and pulp, in household and commercial bleaches, and in treatment of municipal and industrial water supplies.

Dry chlorine is not corrosive to steels, stainless steels, or nickel alloys at ambient temperature. Steel is usable up to about 150 °C (300 °F) and possibly higher under certain conditions. Stainless steels are usable up to about 300 °C (570 °F), and nickel is commonly used up to about 500 °C (930 °F). However, many industrial chlorine environments contain substantial water, particularly those encountered in the manufacture of chlorine prior to the drying operation. Wet chlorine gas is extremely corrosive at temperatures below the dew point, because the condensate is a very acidic and oxidizing mixture.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 is more readily attacked by wet than by dry chlorine at room temperature, especially if condensation is present. At temperatures above 130 °C (265 °F), however, the presence of moisture greatly reduces corrosion of aluminum, and data have shown that larger amounts of water have greater effects. Aluminum appears to be usable to 130 °C (265 °F) at 0.06% water, to 200 °C (390 °F) at 1.5% water, and to 545 °C (1015 °F) at 30% water.

In dry chlorine service, care must be taken when evaluating results for aluminum, because the protective aluminum oxide film may delay the onset of corrosion. In one study, there was a 5-h delay before reaction in dry chlorine at 500 °C (930 °F). Aluminum was reported to be usable up to about 120 °C (250 °F).

Steels. Steel is used for handling dry chlorine, and corrosion rates are generally low. Ignition can be a problem, however, and although some studies have indicated a maximum-use temperature of 205 °C (400 °F), the discussion in one of these same studies suggests that a prudent maximum temperature may be nearer 150 °C (300 °F) because of exotherms from reaction with grease-contaminated equipment. For grease-free and properly cleaned equipment, a maximum-use temperature of 200 °C (390 °F) may be acceptable.

In 8-h tests of steel in chlorine service, corrosion rates below 0.0025 mm/yr (0.1 mil/yr) at up to 245 °C (475 °F) were recorded, but ignition occurred at 250 °C (485 °F). A slightly lower ignition temperature was reported for 16- and 20-h tests. Ignition of steel wool (grade 00) occurred at temperatures as low as 185 °C (365 °F).

Refrigerated liquid chlorine can also be handled in steel, but special care should be taken at potential leak sites, such as at valves and non-welded fittings. Because the chlorine is refrigerated, pipelines and associated equipment become encased in ice formed from the moisture in the air. Chlorine from even small leaks is then trapped beneath the ice, forming wet chlorine gas that is corrosive even at low temperatures. Therefore, Alloy 20 materials are often used for valves and other fittings in refrigerated liquid chlorine equipment, and ordinarily nonwetted parts, such as bonnet bolts in valves, are typically made of more resistant alloys.

Dry chlorine is not corrosive to steels, stainless steels, or nickel alloys at ambient temperatures. It is commonly shipped and handled in carbon steel equipment, with higher alloy materials such as nickel, Monel 400, and Hastelloy C usually used for critical parts. Valves are frequently steel with Monel 400 or Hastelloy C trim and stems. Steel is usable up to about 150 °C (300 °F) and possible higher under certain conditions. Stainless steels are usable up to about 300 °C (570 °F), and nickel is commonly used up to about 500 °C (930 °F). Inconel 600 or low-carbon nickel is often substituted for nickel at temperatures where graphitization may occur. Moisture will greatly accelerate attack of any of these materials, with the additional danger of stress-corrosion cracking of stainless steels.

Tests with various irons and steels in flowing chlorine indicated that ignition occurs at lower temperatures for steels with higher alloy contents, especially for carbon. Ignition at temperatures as low as 220 °C (430 °F) was found for iron containing 0.3% C and 6% other alloy content. This probably accounts for the lower use temperature for cast iron versus steel. Iron alloys with silicon contents in the 10 to 15% range, however, reportedly resisted attack by dry chlorine, but their poor impact properties limit practical applications in such critical service.

Below 250 °C (480 °F), the presence of oxygen and moisture had little effect on iron chlorination rates. Because iron is attacked less rapidly by hydrogen chloride than chlorine, the presence of hydrogen chloride in dry chlorine should have little effect on iron chlorination rates. In practice, however, the use of steel is avoided where moisture may be present.

The temperature limits for many of the alloys correspond to higher corrosion rates than might usually be tolerated for expensive alloys. The rates shown, however, are in most cases higher than those that would occur in prolonged exposures. This is because, for most of the alloys, passivation occurs by the formation of a metal chloride film, after which corrosion decreases rapidly. In many cases, corrosion at higher temperatures is roughly proportional to the vapor pressure of the particular metal chlorides formed.

Stainless Steels. Austenitic stainless steels are significantly more resistant to dry chlorine than steel, aluminum, or copper. Type 304 and type 316 stainless steels may be used at temperatures up to 300 °C (570 °F).

Moisture has a significant effect on corrosion of type 304 and type 316 stainless steels in chlorine. Tests conducted on type 304 in chlorine containing 0.4% water showed rates of approximately 30.5 mm/yr (1200 mils/yr) at 40 °C (105 °F), as opposed to an estimated 0.3 mm/yr (12 mils/yr) at 100 °C (212 °F) in dry chlorine. Corrosion in wet chlorine decreased with increasing temperature until about 370 °C (700 °F), at which point the corrosion was about 4.6 mm/yr (180 mils/yr) and the effect of the moisture disappeared. The detrimental effect of moisture at

low temperatures is believed to exist for chromium and austenitic stainless steels in general, including cast stainless steels. The presence of moisture also increases the possibility of stress-corrosion cracking. Chlorinated water in enclosed, poorly ventilated structures (e.g., indoor swimming pools, water treatment facilities, etc.) can promote atmospheric corrosion of stainless steels, as well as other materials.

Copper. Copper and copper alloys have been found to suffer accelerated attack in chlorine gas saturated with water vapor. Copper alloys do not have adequate corrosion resistance for practical use in moist chlorine at temperatures above 200 °C (390 °F). Water vapor at room temperature was shown to accelerate attack on copper and copper alloys. The same effect was reported on copper at temperatures below 200 °C. Above 250 °C (480 °F), however, water vapor and oxygen in chlorine were reported to reduce attack of copper and to increase its ignition temperature from about 300 °C (570 °F) to about 350 °C (660 °F).

In a study on corrosion of copper in dry chlorine, a maximum-use temperature of 205 °C (400 °F) was suggested. In other work, ignition of copper was observed at temperatures from 260 to 300 °C (500 to 570 °F) at high velocities and at temperatures from 290 to 310 °C (555 to 590 °F) at a velocity of 250 ml/min, but did not occur at 40 ml/min.

Lead. Lead has been found to be resistant to corrosion in dry flowing chlorine at temperatures up to 275 °C (525 °F). The average rates reported were 0.06 mm/yr (2.4 mils/yr) at 200 °C (390 °F), 0.13 mm/yr (5.1 mils/yr) at 250 °C (480 °F), 0.14 mm/yr (5.5 mils/yr) at 275 °C (525 °F), 1.5 mm/yr (59 mils/yr) at 295 °C (565 °F), and 2.5 mm/yr (98 mils/yr) at 310 °C (590 °F).

Magnesium. Dry chlorine causes little or no corrosion of magnesium at room or slightly elevated temperatures. The presence of a small amount of water results in pronounced attack by chlorine. Wet chlorine below the dew point of any aqueous phase causes severe attack of magnesium.

In dry chlorine service, magnesium has been found to perform as well as Chromel A and actually better than Monel 400. A maximum-use temperature of 455 °C (850 °F) has been suggested, but use of magnesium in chlorine is not widespread.

Nickel. Nickel 200 and nickel-base alloys show excellent resistance to corrosion in dry chlorine. A temperature of 500 °C (930 °F) appears to be the upper limit for routine use of nickel in dry chlorine service.

Nickel and nickel alloys are adversely affected, however, by the presence of moisture in chlorine at temperatures up to their maximum-use temperatures in dry chlorine. It has been found that 1.5% water vapor can double the reaction rate between chlorine and nickel; 30% water increases the rate from 2 to 20 times. At temperatures above 550 °C (1020 °F), moisture has been reported to have little effect, but the rates at that temperature make the use of nickel marginal even in dry chlorine. Between 425 and 760 °C (795 and 1400 °F), graphitization of Nickel 200 may occur, and a low-carbon version of nickel with a maximum of 0.02% C is normally used. When sulfur compounds are present, Inconel 600 is often substituted for nickel to avoid intergranular attack.

Inconel 600 and Hastelloy B perform nearly as well as nickel in dry chlorine, and Hastelloy C somewhat less well. Chromel A and Monel 400 perform much better than stainless steels, but not as well as the other alloys mentioned above. Monel 400 is commonly used as trim on valves, but it should be used with care in refrigerated systems. Cast ACI alloy CW-12M (Ni-18Cr-18Mo) was reported to corrode in dry chlorine at 0 to 60 °C (32 to 140 °F) at about the same rate as Hastelloy C. Hastelloy C-276 corrodes 2 to 1000 times faster, and Chlorimet 3 corrodes 100 to 1000 times faster in wet chlorine than in dry. Numerous other nickel, nickel-copper, nickel-chromium-iron, and nickel-chromium-molybdenum alloys are also reported to suffer greatly accelerated attack by wet chlorine at temperatures below the dew point.

Niobium. Niobium is resistant to wet chlorine at temperatures up to about 100 °C (212 °F) and to dry chlorine up to approximately 200 °C (390 °F).

Palladium. Palladium is attacked by chlorine when air is present.

Rhodium. Rhodium is unattacked by chlorine at room temperature, but it may be attacked at elevated temperatures.

Ruthenium. Ruthenium is slowly attacked by saturated aqueous solutions of chlorine.

Silver. Silver is resistant to both dry and moist chlorine.

Tantalum. Tantalum is not attacked by chlorine or by chlorine oxides at ordinary temperatures. It is inert to wet chlorine at temperatures up to 150 °C (300 °F). Tantalum has been reported to give good service in chlorine plus 1.5% water at temperatures up to 375 °C (705 °F) and in chlorine plus 30% water at up to 400 °C (750 °F), but other studies have indicated less satisfactory performance under these conditions.

In dry chlorine, attack on tantalum has been shown to begin at 250 °C (480 °F), to be violent after 35 min at 450 °C (840 °F), and to be instantaneous at 500 °C (930 °F). Pitting of tantalum in a mixture of dry chlorine and anhydrous methanol at 65 °C (150 °F), presumably caused by the presence of halogenated HCOOH contamination, has been reported.

Tin. Tin is readily attacked by chlorine at room temperature.

Titanium. Titanium is well known for its resistance to corrosion by wet chlorine and is used extensively in various types of chlorine-manufacturing equipment, such as wet chlorine compressors. Titanium is perfectly passive if there is enough water in the chlorine, but it ignites, sometimes at temperatures as low as –18 °C (0 °F), if there is not enough water. With sufficient water, titanium is resistant up to at least 175 °C (345 °F) and probably higher.

The minimum amount of water that is required to maintain the passivity of titanium depends on temperature and other factors. The amount of water required at temperatures between 25 and 175 °C (75 and 350 °F) was found to depend on chlorine pressure, temperature, flow rate, purity, and degree of surface abrasion of the titanium. Crude cell chlorine tested under static conditions required about 0.5% water at 125 °C (255 °F) and 1.2% water at 175 °C (350 °F). Less water was required at flow rates above 0.15 m/s (0.5 ft/s). Pure (99.5%) chlorine requires relatively more water—about 0.93% at room temperature and 1.5% at 200 °C (390 °F) under static conditions.

Although titanium is the preferred metallic material for handling wet chlorine and bromine gas environments, rapid, dangerous, exothermic halogenation reactions may occur with titanium in dry chlorine and bromine gas environments. Mechanical damage to metal surfaces to expose fresh metal facilitates reaction with dry chlorine, but thicker oxide films (thermal oxides) tend to retard initiation of the reaction.

Zinc. Dry chlorine does not affect zinc.

Zirconium. Unalloyed zirconium has been found to corrode in wet chlorine at rates of 2 mm/yr (80 mils/yr) at 15 °C (60 °F) and 4.9 mm/yr (192 mils/yr) at 25 °C (75 °F). Another study reported a corrosion rate of over 1.3 mm/yr (50 mils/yr) in room-temperature chlorine containing 0.3% water. Unalloyed zirconium corrodes at less than 0.13 mm/yr (5 mils/yr) in dry chlorine near room temperature. Stress-corrosion cracking of reactor grade zirconium in 0.01 mg/cm^3 of chlorine gas has been reported at temperatures from 360 to 400 °C (680 to 750 °F). In low-pH chlorine gas, zirconium is not subject to crevice attack.

Corrosion Behavior of Various Metals and Alloys in Chlorine

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum alloy 1100	A91100	...	0.06 wt% water in chlorine	...	130 (265)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	0.06 wt% water in chlorine	...	170 (340)	...	3.6 (140)	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	130 (265)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	200 (390)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	290 (555)	...	1.04 (41)	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	320 (610)	...	1.04 (41)	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	350 (660)	...	5300 (210,000)	...	84
Aluminum alloy 1100	A91100	...	1.5 wt% water in chlorine	...	400 (750)	...	21000 (830,000)	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	140 (285)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	170 (340)	...	0.53 (21)	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	290 (555)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	545 (1015)	...	0.5 (20) max	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	615 (1140)	...	5.3 (210)	...	84
Aluminum alloy 1100	A91100	...	30 wt% water in chlorine	...	630 (1165)	...	7800 (311,000)	...	84
Aluminum alloy 1100	A91100	...	Dry	...	150 (300)	...	1.5 (60)	...	83
Aluminum alloy 1100	A91100	...	Dry	...	150 (300)	...	3 (120)	...	83
Aluminum alloy 1100	A91100	...	Dry	...	180 (350)	...	15 (600)	...	83
Aluminum alloy 1100	A91100	...	Dry	...	180 (350)	...	30 (1200)	...	83
Aluminum alloy 1100	A91100	...	Dry. Suggested upper temperature limit for continuous use	...	120 (250)	...	0.76 (30)	...	83
Carbon and alloy steels									
1.25Cr-0.5Mo steel	K11597	...	With nitrogen at 1 atm. Gas velocity = 0.3 cm/s	1	500 (930)	1 h	140 (5515)	...	243
1.25Cr-0.5Mo steel	K11597	...	With nitrogen at 1 atm. Gas velocity = 2.4 cm/s	1	500 (930)	1 h	224 (8825)	...	243
1020	G10200	...	With nitrogen at 1 atm. Gas velocity = 0.3 cm/s	1	260 (500)	1 h	41 (1615)	...	243
1020	G10200	...	With nitrogen at 1 atm. Gas velocity = 0.3 cm/s	1	500 (930)	1 h	267 (10520)	...	243
1020	G10200	...	With nitrogen at 1 atm. Gas velocity = 2.4 cm/s	1	260 (500)	1 h	43 (1695)	...	243
1020	G10200	...	With nitrogen at 1 atm. Gas velocity = 2.4 cm/s	1	500 (930)	1 h	375 (14775)	...	243
5Cr-0.5Mo steel	K41245	...	With nitrogen at 1 atm. Gas velocity = 0.3 cm/s	1	500 (930)	1 h	11.4 (450)	...	243
5Cr-0.5Mo-steel	K41245	...	With nitrogen at 1 atm. Gas velocity = 2.4 cm/s	1	500 (930)	1 h	11.6 (457)	...	243
Carbon steels									
G10100	...	Dry	...	120 (250)	...	0.76 (30)	...	83	
G10100	...	Dry	...	180 (350)	...	1.5 (60)	...	83	
G10100	...	Dry	...	230 (450)	...	15 (600)	...	83	
G10100	...	Dry	...	230 (450)	...	30 (1200)	...	83	
G10100	...	Dry	...	121 (250)	...	.86 (34)	...	257	
G10100	...	Dry	...	177 (350)	...	.18 (7)	...	257	
G10100	...	Dry	...	204 (400)	...	.35 (14)	...	257	
G10100	...	Dry	...	232 (450)	...	1.75 (69)	...	257	
G10100	...	Dry. Suggested upper temperature limit for continuous use	...	205 (400)	...	3 (120)	...	83	
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	Moist	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Questionable	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Questionable	...	93
Ampco 8, aluminum bronze	C61300	...	Dry. Generally suitable. Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Ampco 8, aluminum bronze	C61300	...	Wet. Generally not suitable	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Poor	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Poor	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Questionable	...	93
Deoxidized copper	C12000	...	Dry	...	230 (450)	...	1.5 (60)	...	83
Deoxidized copper	C12000	...	Dry	...	260 (500)	...	15 (600)	...	83
Deoxidized copper	C12000	...	Dry	...	260 (500)	...	3 (120)	...	83
Deoxidized copper	C12000	...	Dry	...	290 (550)	...	30 (1200)	...	83
Deoxidized copper	C12000	...	Dry. Suggested upper temperature limit for continuous use 205°C (400°F)	...	180 (350)	...	0.76 (30)	...	83
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Poor	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Poor	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Poor	...	93
Nickel- silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel- silver	...	...	Moist	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Questionable	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Questionable	...	93
Iron-nickel alloys									
Kovar (29Ni-16Co)	...	...	Dry	...	650 (1200)	...	6.6 (264)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.51 m/s, 0.006% H_2O	...	300 (570)	...	0.53 (21)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.51 m/s, 0.6% H_2O	...	300 (570)	...	0.55 (22)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.51 m/s. Dry	...	300 (570)	...	0.50 (20)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.53 m/s, .006% H_2O	...	400 (750)	...	0.55 (22)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.53 m/s, 0.6% H_2O	...	400 (750)	...	0.58 (23)	...	257

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Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Kovar (29Ni-16Co)	...	...	Flow rate = 0.53 m/s. Dry	...	400 (750)	...	0.53 (21)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.58 m/s, 0.006% H_2O	...	450 (840)	...	0.65 (26)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.58 m/s, 0.6% H_2O	...	450 (840)	...	0.68 (27)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.58 m/s. Dry	...	450 (840)	...	0.60 (24)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.65 m/s, 0.6% H_2O	...	500 (930)	...	0.73 (29)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.69 m/s, 0.006% H_2O	...	500 (930)	...	0.85 (34)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 0.69 m/s. Dry	...	500 (930)	...	0.73 (29)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 1.50 m/s, 0.006% H_2O	...	550 (1020)	...	1.03 (41)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 1.50 m/s, 0.6% H_2O	...	550 (1020)	...	0.83 (33)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 1.50 m/s. Dry	...	550 (1020)	...	1.63 (65)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 2.91 m/s, 0.6% H_2O	...	600 (1110)	...	1.05 (42)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 2.91 m/s. Dry	...	600 (1110)	...	3.2 (428)	...	257
Kovar (29Ni-16Co)	...	...	Flow rate = 2.91 m/s. Dry	...	600 (1110)	...	1.20 (48)	...	257
Irons and alloys									
Cast iron	F10001	...	Dry	...	90 (200)	...	0.76 (30)	...	83
Cast iron	F10001	...	Dry	...	120 (250)	...	1.5 (60)	...	83
Cast iron	F10001	...	Dry	...	230 (450)	...	15 (600)	...	83
Cast iron	F10001	...	Dry	...	230 (450)	...	30 (1200)	...	83
Cast iron	F10001	...	Dry. Suggested upper temperature limit for continuous use	...	180 (350)	...	3 (120)	...	83
Cast iron	F10001	...	Dry	...	93 (200)	...	.86 (34)	...	257
Cast iron	F10001	...	Dry	...	121 (250)	...	.18 (7)	...	257
Cast iron	F10001	...	Dry	...	177 (350)	...	.35 (14)	...	257
Cast iron	F10001	...	Dry	...	232 (450)	...	1.75 (69)	...	257
Miscellaneous									
Gold	P00016	...	Dry	...	120 (250)	...	0.7 (28)	...	250
Gold	P00016	...	Dry	...	120 (250)	...	0.76 (30)	...	83
Gold	P00016	...	Dry	...	150 (300)	...	1.5 (60)	...	83
Gold	P00016	...	Dry	...	150 (300)	...	1.5 (60)	...	250
Gold	P00016	...	Dry	...	175 (345)	...	3.0 (120)	...	250
Gold	P00016	...	Dry	...	180 (350)	...	3 (120)	...	83
Gold	P00016	...	Dry	...	200 (400)	...	15 (600)	...	83
Gold	P00016	...	Dry	...	200 (400)	...	30 (1200)	...	83
Gold	P00016	...	Dry	...	205 (400)	...	31 (1200)	...	250
Gold	P00016	...	Dry	...	22 (72)	...	0.3 (12)	...	250
Gold	P00016	...	Wet	...	22 (72)	...	Poor	...	250
Iridium	...	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Iridium	...	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Lead	L50045	...	...	...	38 (100)	...	0.5 (20) max	...	95
Magnesium	...	...	...	...	454 (850)	...	.077 (30)	...	257
Magnesium	...	...	...	...	482 (900)	...	1.56 (61)	...	257
Magnesium	...	...	...	...	510 (950)	...	3.0 (118)	...	257
Magnesium	...	...	...	...	538 (1000)	...	15.6 (615)	...	257
Magnesium	...	...	...	...	566 (1050)	...	31 (1220)	...	257
Magnesium	...	...	...	100	Room	...	Poor	...	119
Magnesium	...	...	Dry	...	480 (900)	...	1.5 (60)	...	83
Magnesium	...	...	Dry	...	510 (950)	...	3 (120)	...	83
Magnesium	...	...	Dry	...	540 (1000)	...	15 (600)	...	83
Magnesium	...	...	Dry	...	565 (1050)	...	30 (1200)	...	83

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Magnesium	...	...	Dry. Suggested upper temperature limit for continuous use	...	450 (850)	...	0.76 (30)	...	83
Molybdenum	...	Cold rolled, annealed	...	2.1	900 (1650)	...	...	Consumed	211
Osmium	...	...	Dry	...	22 (72)	...	0.25 (10)	...	250
Platinum	P04995	...	...	...	482 (900)	...	0.77 (30)	...	257
Platinum	P04995	...	...	...	510 (950)	...	1.56 (61)	...	257
Platinum	P04995	...	...	...	538 (1000)	...	3.0 (118)	...	257
Platinum	P04995	...	...	...	566 (1050)	...	15.6 (615)	...	257
Platinum	P04995	...	...	...	566 (1050)	...	31 (1220)	...	257
Platinum	P04995	...	Dry	...	22 (72)	...	.25 (10)	...	250
Platinum	P04995	...	Dry	...	510 (950)	...	1.5 (60)	...	83
Platinum	P04995	...	Dry	...	540 (1000)	...	3 (120)	...	83
Platinum	P04995	...	Dry	...	560 (1050)	...	15 (600)	...	83
Platinum	P04995	...	Dry	...	560 (1050)	...	30 (1200)	...	83
Platinum	P04995	...	Dry. Suggested upper temperature limit for continuous use 260°C (500°F)	...	480 (900)	...	0.76 (30)	...	83
Platinum	P04995	...	Moist	...	22 (72)	...	.25 (10)	...	250
Platinum	P04995	...	Saturated in water	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Saturated in water	...	22 (72)	...	.003 (0.1) max	...	250
Ruthenium	...	...	Dry	...	22 (72)	...	.003 (0.1)	...	250
Ruthenium	...	...	Moist	...	22 (72)	...	.003 (0.1)	...	250
Ruthenium	...	...	Saturatd in water	...	22 (72)	...	1.3 (51)	...	250
Silver	P07010	...	Dry	...	100 (212)	...	.05 (2)	...	250
Silver	P07010	...	Dry	...	120 (250)	...	3 (120)	...	83
Silver	P07010	...	Dry	...	230 (450)	...	15 (600)	...	83
Silver	P07010	...	Dry	...	260 (500)	...	30 (1200)	...	83
Silver	P07010	...	Dry	...	40 (100)	...	0.76 (30)	...	83
Silver	P07010	...	Dry	...	65 (150)	...	1.5 (60)	...	83
Silver	P07010	...	Moist	...	100 (212)	...	.05 (2)	...	250
Silver	P07010	...	Saturated in water	...	22 (72)	...	.05 (2)	...	250
Tungsten	...	Cold rolled, annealed	...	2.1	900 (1650)	...	...	Consumed	211
Nickel and alloys									
ACI CW-12M	...	...	...	Saturated	25 (75)	42 d	0.023 (0.90)	...	85
Cabot alloy No. 625	N06625	...	Wet	...	50 (122)	48 h	2.1 (81)	...	67
Cabot alloy No. 625	N06625	...	Wet	...	70 (158)	48 h	4.7 (186)	...	67
Cabot alloy No. 625	N06625	...	Wet	...	Room	48 h	0.003 (0.1) max	...	67
Fecralloy	...	Cold rolled, annealed	...	2.1	900 (1650)	48 h	63	...	211
Fecralloy	...	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	1 h	350	Severe internal corrosion	211
Hastelloy B	N10001	...	Dry	...	510 (950)	...	0.76 (30)	...	83
Hastelloy B	N10001	...	Dry	...	590 (1100)	...	3 (120)	...	83
Hastelloy B	N10001	...	Dry	...	650 (1200)	...	15 (600)	...	83
Hastelloy B	N10001	...	Dry. Suggested upper temperature limit for continuous use	...	540 (1000)	...	1.5 (60)	...	83
Hastelloy C	...	...	Dry	...	480 (900)	...	0.76 (30)	...	83
Hastelloy C	...	...	Dry	...	560 (1050)	...	3 (120)	...	83
Hastelloy C	...	...	Dry	...	650 (1200)	...	15 (600)	...	83

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Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy C	...	...	Dry. Suggested upper temperature limit for continuous use 510°C (950°F)	...	540 (1000)	...	1.5 (60)	...	83
Hastelloy C-276	N10276	...	...	Saturated	25 (75)	56 d	0.0025 (0.10)	...	85
Hastelloy D	...	...	Dry	...	230 (450)	...	1.5 (60)	...	83
Hastelloy D	...	...	Dry	...	290 (550)	...	3 (120)	...	83
Hastelloy D	...	...	Dry. Suggested upper temperature limit for continuous use	...	205 (400)	...	0.76 (30)	...	83
Inconel 600	N06600	...	Dry	...	510 (950)	...	0.76 (30)	...	83
Inconel 600	N06600	...	Dry	...	565 (1050)	...	3 (120)	...	83
Inconel 600	N06600	...	Dry	...	650 (1200)	...	15 (600)	...	83
Inconel 600	N06600	...	Dry	...	680 (1250)	...	30 (1200)	...	83
Inconel 600	N06600	...	Dry. Suggested upper temperature limit for continuous use	...	540 (1000)	...	1.5 (60)	...	83
Inconel 600	N06600	Cold rolled, annealed	...	2.1	900 (1650)	48 h	64	...	211
Inconel 600	N06600	Cold rolled, annealed	...	2.1	900 (1650)	1 h	525	...	211
Inconel 671	...	Cold rolled, annealed	...	2.1	900 (1650)	48 h	...	Consumed	211
Inconel 671	...	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	1 h	876	...	211
Monel 400	N04400	...	...	Saturated	25 (75)	56 d	24 (948)	...	85
Monel 400	N04400	...	Dry	...	450 (850)	...	1.5 (60)	...	83
Monel 400	N04400	...	Dry	...	480 (900)	...	3 (120)	...	83
Monel 400	N04400	...	Dry	...	540 (1000)	...	15 (600)	...	83
Monel 400	N04400	...	Dry	...	540 (1000)	...	30 (1200)	...	83
Monel 400	N04400	...	Dry. Suggested upper temperature limit for continuous use 420°C (800°F)	...	400 (750)	...	0.76 (30)	...	83
Ni-20Cr-1Si	N06009	...	Dry	...	480 (900)	...	1.5 (60)	...	83
Ni-20Cr-1Si	N06009	...	Dry	...	540 (1000)	...	3 (120)	...	83
Ni-20Cr-1Si	N06009	...	Dry	...	620 (1150)	...	15 (600)	...	83
Ni-20Cr-1Si	N06009	...	Dry. Suggested upper temperature limit for continuous use 450°C (850°F)	...	425 (800)	...	0.76 (30)	...	83
Ni-27%Cr	...	Cold rolled, annealed	...	2.1	900 (1650)	48 h	58	...	211
Ni-27%Cr	...	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	48 h	44	...	211
Ni-27%Cr-4%Al	...	Cold rolled, annealed	...	2.1	900 (1650)	48 h	18	...	211
Ni-27%Cr-4%Al	...	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	48 h	15	...	211
Nickel 201	N02201	...	Dry	...	510 (950)	...	0.76 (30)	...	83
Nickel 201	N02201	...	Dry	...	590 (1100)	...	3 (120)	...	83
Nickel 201	N02201	...	Dry	...	650 (1200)	...	15 (600)	...	83
Nickel 201	N02201	...	Dry	...	680 (1250)	...	30 (1200)	...	83
Nickel 201	N02201	...	Dry. Suggested upper temperature limit for continuous use	...	540 (1000)	...	1.5 (60)	...	83
Refractory metals and alloys									
44Co-31Cr-13W	...	As cast	Based on five 24-h test periods	100	Room	...	4.9 (194)	...	53
44Co-31Cr-13W	...	As cast	Wet. Average of five 24-h periods	100	Room	...	4.85 (194)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled	Based on five 24-h test periods	100	Room	...	6.27 (251)	...	53

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Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled	Wet. Average of five 24-h periods	100	Room	...	6.27 (251)	...	53
50Co-20Cr-15W-10Ni	...	...	...	100	Room	...	0.002 (0.1)	...	53
50Co-20Cr-15W-10Ni	...	Cast specimens	Wet. Average of five 24-h periods	100	Room	...	0.002 (0.1)	...	53
53Co-30Cr-4.5W	...	As cast	Based on five 24-h test periods	100	Room	...	8.75 (350)	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Wet. Average of five 24-h periods	100	Room	...	8.75 (350)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F)	Based on five 24-h test periods	100	Room	...	11.37 (455)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled; cast specimen	Wet. Average of five 24-h periods	100	Room	...	11.37 (455)	...	53
Cb alloy	...	Wrought 50% V, 50% Cb; arc melted	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Cb alloy	...	Wrought 8% Ti, bal Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Cb alloy	R04261	Wrought 0.75% Zr, bal Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Cb	R04210	Wrought 100% Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Cb	R04210	Wrought 100% Cb; electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Cb	R04210	Wrought 100% Cb; lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Haynes No.25	R30605	...	Wet. Specimens prepared from 12-gage, solution heat-treated sheet	...	Room	24-h	0.01 (0.1) max	...	68
Hf-17.3Zr	...	...	...	Saturated	Boiling	2 d	0.0025 (0.1) max	...	11
Hf-17.3Zr	...	...	...	Saturated	Boiling	4 d	0.005 (0.2)	...	11
Hf-2.9Zr	...	...	...	Saturated	Boiling	2 d	0.015 (0.6)	...	11
Hf-2.9Zr	...	...	...	Saturated	Boiling	4 d	0.005 (0.2)	...	11
Hf-47.4Zr	...	...	...	Saturated	Boiling	2 d	0.0025 (0.1) max	...	11
Hf-47.4Zr	...	...	...	Saturated	Boiling	4 d	0.0025 (0.1) max	...	11
Hf-59.5Zr	...	...	...	Saturated	Boiling	2 d	Resistant	...	11
Hf-59.5Zr	...	...	...	Saturated	Boiling	4 d	0.0025 (0.1) max	...	11
Hf-81.4Zr	...	...	...	Saturated	Boiling	2 d	0.0025 (0.1) max	...	11
Hf-81.4Zr	...	...	...	Saturated	Boiling	4 d	0.0025 (0.1) max	...	11
Multimet	R30155	Solution heat-treated	Wet	...	Room	24-h	4.57 (180)	...	68
Tantalum	R05210	...	Wet	...	75 (167)	...	Resistant	...	42
Tantalum	R05210	Commercial sheet	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38

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Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Tantalum	R05210	High purity	Average of three 48-h periods	Wet	Room	48 h	0.025 (1) max	...	38
Titanium	...	...	Gas. Dry. Containing <0.5% H_2O	...	Room	...	Questionable	...	90
Titanium	...	...	Gas. Wet. Containing >0.7% H_2O	...	Room	...	Resistant	...	90
Titanium	...	...	Gas. Wet. Containing >0.95% H_2O	...	140 (284)	...	Resistant	...	90
Titanium	...	...	Gas. Wet. Containing >1.5% H_2O	...	200 (392)	...	Resistant	...	90
Titanium, grade 2	R50400	...	...	Saturated	25 (75)	56 d	0.0005 (0.02)	...	85
Titanium, grade 7	R52400	...	Wet	...	25 (75)	...	Resistant	...	33
Zr702	R60702	...	Gas (more than 0.13% H_2O)	100	94 (200)	...	1.3 (50) min	...	15
Zr702	R60702	...	Gas, dry	100	Room	...	0.13 (5) max	...	15
Zr702	R60702	...	In water	Saturated	75 (165)	...	1.3 (50) min	...	15
Zr702	R60702	...	In water	Saturated	Room	...	1.3 (50) min	...	15
Stainless steels									
20Cb-3	N08020	...	...	Saturated	25 (75)	56 d	0.008 (0.30)	...	85
301	S30100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	Moist	...	100 (212)	...	Poor	Pitting	253
301	S30100	...	Moist	...	20 (68)	...	Poor	Pitting	253
302	S30200	...	Dry	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	Moist	...	100 (212)	...	Poor	Pitting	253
302	S30200	...	Moist	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Moist	...	100 (212)	...	Poor	Pitting	253
303	S30300	...	Moist	...	100 (212)	...	Poor	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Dry	...	315 (600)	...	1.5 (60)	...	83
304	S30400	...	Dry	...	340 (650)	...	3 (120)	...	83
304	S30400	...	Dry	...	400 (750)	...	15 (600)	...	83
304	S30400	...	Dry	...	450 (850)	...	30 (1200)	...	83
304	S30400	...	Dry. Suggested upper temperature limit for continuous use 310°C (600°F)	...	290 (550)	...	0.76 (30)	...	83
304	S30400	...	Moist	...	100 (212)	...	Poor	Pitting	253
304	S30400	...	Moist	...	20 (68)	...	Poor	Pitting	253
304L	S30403	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	Moist	...	100 (212)	...	Poor	Pitting	253
304L	S30403	...	Moist	...	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	Moist	...	100 (212)	...	Poor	Pitting	253
304LN	S30453	...	Moist	...	20 (68)	...	Poor	Pitting	253
310	S31000	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	1 h	350	...	211
310	S31000	Cold rolled, annealed	Preoxidized	2.1	900 (1650)	48 h	55	...	211
316	S31600	...	...	Saturated	25 (75)	56 d	0.008 (0.30)	...	85
316	S31600	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Dry	...	345 (650)	...	1.5 (60)	...	83
316	S31600	...	Dry	...	400 (750)	...	3 (120)	...	83
316	S31600	...	Dry	...	450 (850)	...	15 (600)	...	83
316	S31600	...	Dry	...	480 (900)	...	30 (1200)	...	83

(Continued)

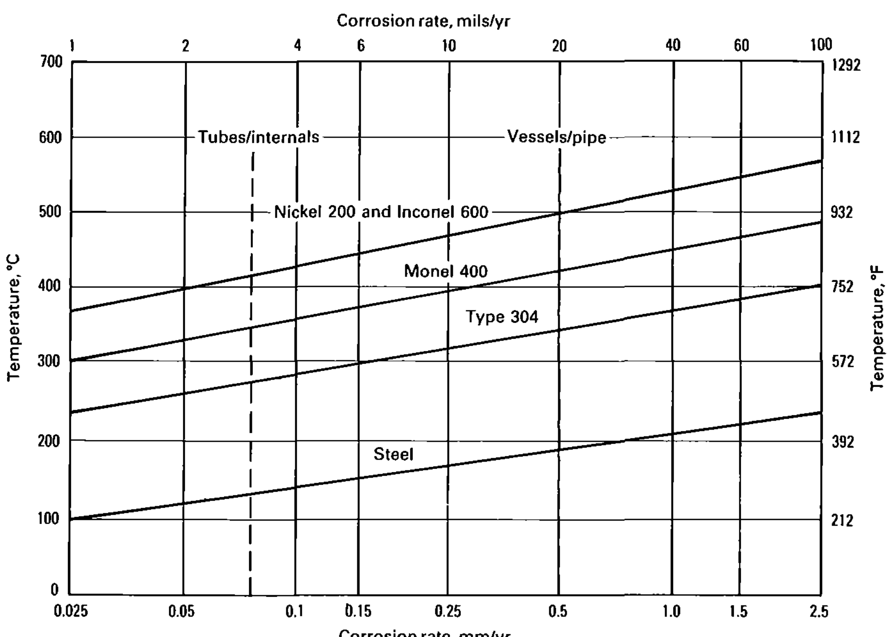
Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Dry. Suggested upper temperature limit for continuous use 340°C (650°F)	...	310 (600)	...	0.76 (30)	...	83
316	S31600	...	Moist	...	100 (212)	...	Poor	Pitting	253
316	S31600	...	Moist	...	20 (68)	...	Poor	Pitting	253
316F	S31620	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	Moist	...	100 (212)	...	Poor	Pitting	253
316F	S31620	...	Moist	...	20 (68)	...	Poor	Pitting	253
316L	S31603	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Moist	...	100 (212)	...	Poor	Pitting	253
316L	S31603	...	Moist	...	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Moist	...	100 (212)	...	Poor	Pitting	253
316LN	S31653	...	Moist	...	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	Moist	...	100 (212)	...	Poor	Pitting	253
316Ti	S31635	...	Moist	...	20 (68)	...	Poor	Pitting	253
317	S31700	...	Chemical processing; field or pilot plant test; no aeration. Chlorine, hydrochloric acid, naphthalene, naphthalene chloride (vapors)	...	166 (330)	52 d	0.035 (1.4)	...	89
317	S31700	...	Chemical processing; lab test; no aeration; no agitation. Chlorine, hydrochloric acid, propionic acid (chlorinator)	...	20 (68)	2 d	7.0 (280)	...	89
317	S31700	...	Chemical processing; lab test; no aeration; no agitation. Chlorine, hydrochloric acid, propionic acid	...	20 (68)	1 d	0.16 (6.4)	...	89
317L	S31703	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Moist	...	100 (212)	...	Poor	Pitting	253
317L	S31703	...	Moist	...	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Moist	...	100 (212)	...	Poor	Pitting	253
317LN	S31725	...	Moist	...	20 (68)	...	Poor	Pitting	253
321	S32100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	Moist	...	100 (212)	...	Poor	Pitting	253
321	S32100	...	Moist	...	20 (68)	...	Poor	Pitting	253
329	S32900	...	Dry	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Moist	...	100 (212)	...	Poor	Pitting	253
329	S32900	...	Moist	...	20 (68)	...	Poor	Pitting	253
347	S34700	...	Dry	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	Moist	...	100 (212)	...	Poor	Pitting	253
347	S34700	...	Moist	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
403	S40300	...	Moist	...	100 (212)	...	Poor	Pitting	253
403	S40300	...	Moist	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	Dry	...	20 (68)	...	Resistant	Pitting	253
405	S40500	...	Moist	...	100 (212)	...	Poor	Pitting	253
405	S40500	...	Moist	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	Dry	...	20 (68)	...	Resistant	Pitting	253
409	S40900	...	Moist	...	100 (212)	...	Poor	Pitting	253
409	S40900	...	Moist	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
410	S41000	...	Gas, wet and dry	...	Room	...	Poor	...	121
410	S41000	...	Moist	...	100 (212)	...	Poor	Pitting	253
410	S41000	...	Moist	...	20 (68)	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorine (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	With nitrogen at 1 atm. Gas velocity = 0.3 cm/s	1	500 (930)	1 h	6.1 (240)	...	243
410	S41000	...	With nitrogen at 1 atm. Gas velocity = 2.4 cm/s	1	500 (930)	1 h	5.4 (213)	...	243
416	S41600	...	Dry	...	20 (68)	...	Resistant	Pitting	253
416	S41600	...	Moist	...	100 (212)	...	Poor	Pitting	253
416	S41600	...	Moist	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
420	S42000	...	Moist	...	100 (212)	...	Poor	Pitting	253
420	S42000	...	Moist	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
430	S43000	...	Moist	...	100 (212)	...	Poor	Pitting	253
430	S43000	...	Moist	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	Dry	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	Moist	...	100 (212)	...	Poor	Pitting	253
434	S43400	...	Moist	...	20 (68)	...	Poor	Pitting	253
446	S44600	...	Dry	...	300 (572)	...	0.2 (7.9)	...	257
446	S44600	...	Dry	...	350 (680)	...	2 (79)	...	257
446	S44600	...	Dry	...	440 (824)	...	40 (1576)	...	257
446	S44600	...	Dry	...	540 (1004)	...	700 (27580)	...	257
ACI CD-4MCu	J93370	...	...	Saturated	25 (75)	42 d	0.06 (2.5)	Crevice corrosion	85
ACI CF-8M	J92900	...	...	Saturated	25 (75)	42 d	0.013 (0.50)	Crevice corrosion	85
ACI CN-7M	J95150	...	...	Saturated	25 (75)	42 d	0.05 (1.8)	Crevice corrosion	85
F51	S31803	...	Dry	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Moist	...	100 (212)	...	Poor	Pitting	253
F51	S31803	...	Moist	...	20 (68)	...	Poor	Pitting	253



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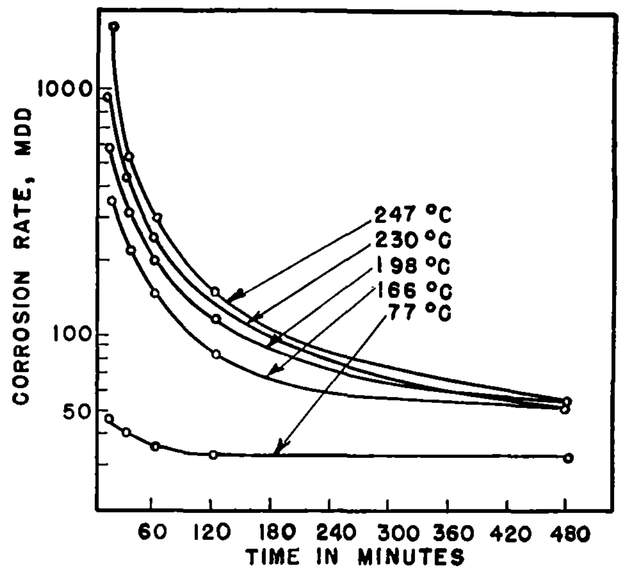
Various alloys. Design guidelines for use in dry chlorine. Source: Chemical Processing Industry.



Carbon steel. Rate of corrosion (weight loss) of mild steel in contact with commercial chlorine (0.005% moisture) as a function of time. Source: H.H. Uhlig, "Iron and Steel," in *The Corrosion Handbook*, H.H. Uhlig, Ed., John Wiley & Sons, New York, 1948, 142.

Chlorine Dioxide

Chlorine dioxide, ClO_2, is a yellow-reddish gas. It is a very effective bleaching and water treatment agent. Chlorine dioxide is prepared by the reaction of chlorine and sodium chlorite. It is quite unstable and is commonly prepared immediately before use.

Corrosion Behavior of Various Metals and Alloys in Chlorine Dioxide

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Alloy 825	N08825	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Chlorine dioxide gas	...	82 (180)	45 d	1.4 (56)	...	89
Alloy 825	N08825	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight ot moderate agitation. Plus saturated water solution	~7.2	3 (38)	70 d	0.08 (3.2)	...	89
Refractory metals and alloys									
Titanium	...	...	...	5	82 (180)	...	0.003 (0.12) max	...	90
Titanium	...	...	...	10	70 (158)	...	0.03 (1.2)	...	90
Titanium	...	...	In steam	5	99 (211)	...	Resistant	...	90
Titanium	...	...	Plus HOCl	15	43 (110)	...	Resistant	...	27
Titanium	...	...	Plus HOCl, $H_2O + Cl_2$	15	43 (110)	...	Resistant	...	90

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorine Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	Plus steam	5	100 (212)	...	0.005 (0.2)	...	27
Stainless steels									
304	S30400	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus methanol, 32% sodium perchlorate, sulfuric acid 60° Be	...	57 (135)	14.5 d	14 (550) min	...	89
304	S30400	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus saturated water solution	~4-5	2 (36)	14.5 d	0.13 (5.1)	Severe pitting	89
304	S30400	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Chlorine dioxide spent liquor, 45% sulfuric acid, 20 g/L sodium chlorate	...	68 (155)	14.6 d	0.04 (1.6)	Severe pitting	89
304	S30400	...	Pulp and paper processing; field or pilot plant test; strong aeration; rapid agitation. Chlorine dioxide gas and condensed solution	10.8	66 (150)	14.5 d	8.3 (330)	...	89
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Chlorine dioxide gas and condensed solution	10.8	66 (150)	14.5 d	7.3 (290)	Severe pitting	89
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus methanol, 32% sodium perchlorate, sulfuric acid 60° Be	...	57 (135)	14.5 d	3.8 (150)	Severe pitting	89
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Low-carbon grade (0.03% C max). Plus saturated water solution	~7.2	3 (38)	70 d	0.13 (5.2)	Severe pitting	89
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus saturated water solution	~4-5	2 (36)	14.5 d	.003 (0.1)	...	89
316	S31600	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Chlorine dioxide spent liquor, 45% sulfuric acid, 20 g/L sodium chlorate	...	68 (155)	14.6 d	0.003 (2.5)	...	89
317	S31700	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Chlorine dioxide gas	...	82 (180)	45 d	Poor	...	89
317	S31700	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus saturated water solution	~7.2	3 (38)	70 d	0.02 (0.9)	...	89
Carpenter 20	...	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus saturated water solution	~7.2	3 (38)	70 d	0.07 (2.6)	Moderate pitting	89
Carpenter 20	...	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Cast specimens. Plus methanol, 32% sodium perchlorate, sulfuric acid 60° Be	...	57 (135)	14.5 d	0.68 (27)	Severe pitting	89
Carpenter 20	...	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Cast specimens. Plus saturated water solution	~4-5	2 (36)	14.5 d	0.02 (0.7)	...	89
Carpenter 20	...	...	Pulp and paper processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Cast specimens. Chlorine dioxide spent liquor, 45% sulfuric acid, 20 g/L sodium chlorate	...	68 (155)	14.6 d	0.03 (1.1)	...	89

Chlorine Water

Chlorine dissolved in water forms a mixture of HCl and hypochlorous acid (HClO). The latter is very oxidizing, which makes the mixture extremely corrosive. Relatively little information is available on corrosion in water containing substantial levels of chlorine, especially near saturation. Aluminum was reported to be unsuitable in HClO and to be attacked with extensive pitting in chlorine-water environments. Zirconium was found to corrode at less than 0.025 mm/yr (1 mil/yr) in chlorine-saturated water.

Corrosion of several alloys in chlorine-saturated water at 25 °C (75 °F) was investigated, and the results show that rates are generally low for the chromium-containing alloys tested and for titanium. Only Monel 400 showed a very high rate (24 mm/yr, or 948 mils/yr), which is to be expected because of its sensitivity to oxidants. No large difference in performance between cast alloys and their wrought equivalents was found, except for crevice attack on ACI CF-8M, CN-7M, and CD-4MCu.

Related tests were performed in chlorine ice at –20 °C (–4 °F). The results show that corrosion rates for chromium-containing alloys are below 0.0025 mm/yr (0.1 mils/yr), except for ACI CW-12M at 0.0038 mm/yr (0.15 mil/yr). Higher, but not unacceptable, rates were found for steel, N-12M, and M-35. These alloys are sensitive to oxidants in acidic environments, which explains their poorer performance.

Corrosion Behavior of Various Metals and Alloys in Chlorine Water

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Zr702	R60702	...	...	...	100 (212)	...	0.05 (2) max	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Good	Pitting	253
302	S30200	...	...	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Good	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Good	Pitting	253
316	S31600	...	...	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Good	Pitting	253
321	S32100	...	...	...	20 (68)	...	Good	Pitting	253
329	S32900	...	...	...	20 (68)	...	Good	Pitting	253
347	S34700	...	...	...	20 (68)	...	Good	Pitting	253
403	S40300	...	...	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	...	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Good	Pitting	253

Chloroacetic Acid

Chloroacetic acid, $CH_2ClCOOH$, also known as monochloroacetic acid, is a colorless solid with a boiling point of 189 °C (372 °F). It is used in manufacturing dyes and in medicine.

Corrosion Behavior of Various Metals and Alloys in Chloroacetic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	4
Refractory metals and alloys									
Titanium	...	...	...	30	80 (176)	...	0.02 (0.8)	...	90
Titanium	...	...	...	100	Boiling	...	0.013 (0.52)	...	90
Titanium	...	...	...	30	80 (176)	...	0.02 (0.8)	...	90
Titanium	...	...	...	100	Boiling	...	0.013 (0.52)	...	90
Stainless steels									
301	S30100	...	...	50	20 (68)	...	Good	Pitting	253
302	S30200	...	...	50	20 (68)	...	Good	Pitting	253
303	S30300	...	...	50	20 (68)	...	Good	Pitting	253
303	S30300	...	...	50	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	50	20 (68)	...	Good	Pitting	253
304	S30400	...	...	All	21 (70)	...	Poor	...	121
304	S30400	...	...	All	21 (70)	...	Poor	...	121
304	S30400	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.24 (9.7)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.24 (9.7)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1)	Crevice attack	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1)	Crevice attack	89
304	S30400	...	Chemical processing; slight to moderate aeration	100	19-21 (66-70)	3 d	0.33 (13)	Slight pitting	89
304	S30400	...	Chemical processing; slight to moderate aeration; slight to moderate agitation	100	19-21 (66-70)	3 d	0.33 (13)	Slight pitting	89
304L	S30403	...	...	50	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	50	20 (68)	...	Good	Pitting	253
316	S31600	...	...	50	20 (68)	...	Good	Pitting	253
316	S31600	...	...	All	21 (70)	...	Poor	...	121
316	S31600	...	...	All	21 (70)	...	Poor	...	121
316	S31600	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.06 (2.5)	...	89
316	S31600	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.06 (2.5)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chloroacetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; slight to moderate aeration	100	19-21 (66-70)	3 d	0.005 (0.2)	...	89
316	S31600	...	Chemical processing; slight to moderate aeration; slight to moderate aeration	100	19-21 (66-70)	3 d	0.005 (0.2)	...	89
316F	S31620	...	...	50	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	50	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	50	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	50	20 (68)	...	Good	Pitting	253
317	S31700	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.05 (2)	...	89
317	S31700	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.05 (2.0)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	Crevice attack	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	Crevice attack	89
317L	S31703	...	...	50	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	50	20 (68)	...	Good	Pitting	253
321	S32100	...	...	50	20 (68)	...	Good	Pitting	253
329	S32900	...	...	50	20 (68)	...	Good	Pitting	253
347	S34700	...	...	50	20 (68)	...	Good	Pitting	253
403	S40300	...	...	50	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	50	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	50	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	50	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	All	21 (70)	...	Poor	...	121
410	S41000	...	...	All	21 (70)	...	Poor	...	121
416	S41600	...	...	50	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	50	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	50	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	All	21 (70)	...	Poor	...	121
430	S43000	...	...	All	21 (70)	...	Poor	...	121
434	S43400	...	...	50	20 (68)	...	Questionable	Pitting	253
Carpenter 20	...	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.045 (1.8)	...	89
Carpenter 20	...	...	Chemical processing ; field or pilot plant test; no aeration; no agitation. Plus 22% water	78	50-60 (122-140)	17 d	0.045 (1.8)	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; no agitation. Plus 22% water	78	10-25 (50-77)	17 d	0.003 (0.1) max	...	89
F51	S31803	...	...	50	20 (68)	...	Good	Pitting	253

Chlorobenzene

Chlorination of benzene in the presence of a catalyst ($FeCl_3$ or $AlCl_3$) yields chlorobenzene as the first product. Substitution with a second Cl yields ortho, para, or meta dichlorobenzene. Eventually all the hydrogens can be substituted to give hexachlorobenzene, C_6Cl_6. In the presence of ultraviolet light, the chlorination of benzene yields benzene hexachloride, $C_6H_6Cl_6$, a derivative of cyclohexane.

Corrosion Behavior of Various Metals and Alloys in Chlorobenzene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	20 (68)	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Good	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Questionable	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	20 (68)	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	20 (68)	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	20 (68)	...	Questionable	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Poor	...	253
405	S40500	...	...	Anhydrous	20 (68)	...	Questionable	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Poor	...	253
409	S40900	...	...	Anhydrous	20 (68)	...	Questionable	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Poor	...	253
410	S41000	...	...	Anhydrous	20 (68)	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorobenzene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	Anhydrous	Boiling	...	Poor	...	253
416	S41600	...	...	Anhydrous	20 (68)	...	Questionable	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Poor	...	253
420	S42000	...	...	Anhydrous	20 (68)	...	Questionable	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Poor	...	253
430	S43000	...	...	Anhydrous	20 (68)	...	Good	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Questionable	...	253
434	S43400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Questionable	...	253
F51	S31803	...	...	Anhydrous	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Chloroform

Chloroform, CCl_3, also known as trichloromethane, formyl trichloride, and methenyl trichloride, is a colorless, nonflammable liquid with a boiling point of 61.2 °C (142 °F). Chloroform is used as a solvent, in medicine, and for organic synthesis.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 was found to be resistant to chloroform with a trace of water. However, in the same test using temperatures up to the boiling point of 61 °C (142 °F), anhydrous chloroform was found to be corrosive to alloy 1100.

Corrosion Behavior of Various Metals and Alloys in Chloroform

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	Generally suitable. Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chloroform (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	...	24-62 (75-143)	...	0.5 (20) max	...	95
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Silver	P07010	...	Dry or wet	...	Boiling	...	0.05 (2) max	...	10
Refractory metals and alloys									
Titanium	...	...	...	100	Boiling	...	Resistant	...	20
Titanium	...	...	...	Vapor	Boiling	...	0.000 (0.000)	...	90
Titanium	...	...	...	Liquid	Boiling	...	0.000 (0.000)	...	90
Titanium	...	...	Plus 50% HNO_3	50	95 (203)	...	0.000 (0.000)	...	90
Titanium	...	...	Plus water	50	Boiling	...	0.12 (4.7)	...	20
Stainless steels									
301	S30100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	20 (68)	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	20 (68)	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	20 (68)	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	20 (68)	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chloroform (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	20 (68)	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Chlorosulfonic Acid

Chlorosulfonic acid, $ClSO_3H$, also known as chlorosulfuric acid and sulfuric chlorohydrin, is an oily liquid with a boiling point of 158 °C (316 °F). It is formed from sulfur trioxide and hydrogen chloride, but decomposes in water to form hydrochloric acid and sulfuric acid. It is a vigorous dehydrating agent and is used in manufacturing synthetic drugs, poison gas, and saccharin.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. (99.5%) is resistant to chlorosulfonic acid at room temperature up to 70 °C. It is used in reaction vessels, stirrers, and feed pipes for the sulphonation of aliphatic alcohols. Aluminum is resistant to chlorosulfonic acid at room temperature and is used in vessels and pipes for so-called fog-forming acid (mixture of chlorosulfonic acid with approximately 50% sulfur trioxide). Aluminum is unusable at room temperature in the presence of water.

Copper. Copper bronze (without zinc) is fairly resistant to chlorosulfonic acid at temperatures up to 150 °C, if water and air are excluded. It is used in boilers in the manufacture of toluenesulfonyl chloride from toluene and chlorosulfonic acid.

Irons and Steels. Iron (pure), cast iron, and steel are resistant to chlorosulfonic acid at room temperature and up to 130 °C, if water is excluded. It is used in vessels, barrels, pipes for transportation and shipping of chlorosulfonic acid and also in mixture with sulfur trioxide for mild steel. Irons are resistant to corrosion at 0 °C and are used for frederking vessels of cast iron for the manufacture of *o*-toluenesulfonyl chloride from toluene and chlorosulfonic acid. Irons are fairly resistant at 180 °C and are used in reaction vessels of mild steel for the manufacture of chlorosulfonic acid from contact gas (6 to 7% sulfur trioxide, balance mainly nitrogen) and hydrogen chloride. The condensers for the hot gaseous chlorosulfonic acid and absorbers (98% sulfuric acid) are also made of mild steel. Iron is unusable at room temperature, if water is present. It is not particularly resistant at 140 °C, but is used with mixtures of 98% chlorosulfonic acid, 1.5% sulfuric acid, and 0.5% hydrochloric acid. Cast silicon-irons (containing more than 14.5% silicon), such as Durichlor, are resistant to chlorosulfonic acid at room temperature.

Stainless Steels. Stainless steels containing approximately 17% chromium and those containing approximately 17% chromium with small additions of molybdenum behave like unalloyed steel. Chlorosulfonic acid is stored in carbon steel and stainless steel.

Austenitic Steels. Stabilized austenitic chromium-nickel steels containing 18 to 20% chromium and 8 to 11% nickel and those containing 16 to 18% chromium, 10 to 14% nickel, and 2.0 to 3.0% molybdenum behave like unalloyed steel in the presence of chlorosulfonic acid. The corrosion rate at room temperature is <0.1 mm/yr, but carries the risk of pitting in the presence of moisture.

Highly alloyed austenitic steels, such as Carpenter 20, are resistant to chlorosulfonic acid from room temperature to 50 °C, as well as to mixtures of 98% chlorosulfonic acid, 1.5% sulfuric acid, and 0.5% hydrochloric acid.

Lead. Lead is fairly resistant to corrosion by chlorosulfonic acid at room temperature. The maximum corrosion rate for lead is 0.8 mm/yr. It is also fairly resistant at 20 °C and is used in decomposition vessels for the elimination of the surplus of chlorosulfonic acid in sulphonation mixtures by adding water (hard lead).

Nickel. Nickel is fairly resistant to chlorosulfonic acid at room temperature, and has a corrosion rate of 0.05 to 0.50 mm/yr. Nickel-chromium alloys, such as Inconel, behave like nickel in the presence of chlorosul-

fonic acid. Monel alloys behave like nickel in the presence of chlorosulfonic acid.

Nickel-molybdenum alloys, such as Hastelloy B, Chlorimet 2, Bergit B, and Euzonit 70, are resistant to chlorosulfonic acid from room temperature up to 140 °C, whether or not moisture is present. They are resistant from room temperature to the boiling point and are used in sulphonation vessels of Hastelloy B for alkyl-aryl organics. These alloys are resistant at 40 °C and are used with mixtures of 45% chlorosulfonic acid, 50% sulfur trioxide, and 5% sulfuric acid in the manufacture of smoke screens, as well as for valves and pumps of Hastelloy B. Nickel-molybdenum alloys are resistant at 100 °C and are used with mixtures of 45% chlorosulfonic acid, 50% sulfur trioxide, 5% sulfuric acid. The corrosion rate for Hastelloy B is <0.05 mm/yr.

Platinum. Platinum, its alloys and less common metals, like gold, are resistant from room temperature up to the boiling point of chlorosulfonic acid. Platinum, gold, and tantalum are resistant up to 100 °C, with a corrosion rate of <0.05mm/yr.

Tin. Chlorosulfonic acid reacts rapidly with tin.

Corrosion Behavior of Various Metals and Alloys in Chlorosulfonic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	...	100	30 (86)	24 h	.06 (2.4)	...	258
Carbon steel	G10100	...	...	90	30 (86)	24 h	0.4 (16)	...	258
Carbon steel	G10100	...	...	70	30 (86)	24 h	0.6 (24)	...	258
Carbon steel	G10100	...	...	60	30 (86)	24 h	0.8 (32)	...	258
Carbon steel	G10100	...	...	50	30 (86)	24 h	1.9 (75)	...	258
Carbon steel	G10100	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	.077 (3.0)	...	258
Carbon steel	G10100	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.0020 (.08)	...	258
Miscellaneous									
Chemical lead	L51120	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	1.2 (47) max	...	258
Chemical lead	L51120	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.015 (0.6)	...	258
Lead	L50045	During storage of chlorosulfonic acid + 50% SO_3	...	50	...	...	0.015 (0.6)	...	48
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Alloy 400	N04400	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	.0008 (.03)	...	258
Alloy 400	N04400	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.0003 (.01)	...	258
Alloy 600	N06600	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	.0003 (.01)	...	258
Alloy 600	N06600	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.0003 (.01)	...	258
Nickel alloy	N10001	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.0005 (.02)	...	258
Nickel 200	N02200	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	.0010 (.04)	...	258
Nickel 200	N02200	...	With 50% sulfur trioxide. In vapor phase	50	30 (86)	145 d	.0005 (.02)	...	258
Nickel alloy	N10001	...	With 50% sulfur trioxide. In liquid phase	50	30 (86)	145 d	.0005 (.02)	...	258
Refractory metals and alloys									
Titanium	...	...	...	100	Room	...	0.3 (12)	...	90
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Poor	Pitting	253
301	S30100	...	...	10	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	10	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	10	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	10	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	10	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	10	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	10	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	10	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	10	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	10	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	10	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chlorosulfonic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	10	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	10	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	10	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	10	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	10	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	10	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	10	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	10	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	10	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	10	20 (68)	...	Poor	Pitting	253
317L	S31703	...	...	10	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	10	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	10	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	10	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	10	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	10	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	10	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	10	20 (68)	...	Resistant	Pitting	253
403	S40300	...	...	10	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	10	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	10	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	10	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	10	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	10	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	10	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	10	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	10	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	10	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	10	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	10	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	10	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	10	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	10	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	10	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	10	20 (68)	...	Resistant	Pitting	253

Chromic Acid

Chromic acid, H_2CrO_4, exists only in solution. The hydrate of chromium oxide, it is used in electroplating baths.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aqueous solutions of chromic acid in concentrations up to 0.1*N* at ambient temperature had no effect on aluminum alloy 1100 in laboratory tests.

Copper. Aluminum bronzes should be avoided in the service of chromic acid.

Lead. Lead has high corrosion resistance to chromic acid and is widely used in its manufacture and handling. Lead performs well at acid concentrations up to 95% at ambient temperatures, up to 85% at 220 °C (428 °F), and up to 93% at 150 °C (302 °F). Below a concentration rate of 5%, the corrosion rate increases, but it is still relatively low. Lead exhibits the same excellent corrosion resistance to higher concentrations of chromic acid. In general, lead is also resistant to solutions containing salts of chromic acid.

Magnesium. Magnesium and its alloys are attacked very slowly by pure chromic acid. With the addition of the chloride ion in the chromic acid, the corrosion rate increases markedly. A boiling solution of 20% chromic acid is often used to cleanse corrosion products from magnesium alloys without endangering the base metal.

Titanium. Titanium alloys generally are highly resistant to chromic acid over a wide range of temperatures and concentrations.

Corrosion Behavior of Various Metals and Alloys in Chromic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Questionable	...	92
Aluminum alloys	...	...	Solution	...	20 (68)	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	0.5 (20) max	...	95
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Silver	P07010	...	...	All	100 (212)	...	0.05 (2) max	...	4
Silver	P07010	...	...	All	100 (212)	...	0.05 (2) max	...	4
Tin	...	...	...	80	20 (68)	...	Resistant	...	94
Tin	...	...	...	80	60 (140)	...	Resistant	...	94
Tin	...	...	...	80	100 (212)	...	Resistant	...	94
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	7 d	0.041 (1.6)	No pitting	44
Inconel 601	N06601	...	Average of two tests	5	80 (176)	7 d	0.091 (3.6)	...	64
Inconel 690	N06690	...	...	5	80 (176)	...	0.13 (5)	...	57
Refractory metals and alloys									
44Co-31Cr-13W	...	As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.025 (1)	...	53

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
44Co-31Cr-13W	...	As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.025 (1)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	...	10	65 (150)	...	0.625 (25)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	...	2	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	...	10	65 (150)	...	0.625 (25)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	...	...	10	65 (150)	...	0.125 (5)	...	53
50Co-20Cr-15W-10Ni	...	...	...	2	65 (150)	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.125 (5)	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.7 (28)	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.7 (28)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	...	2	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.57 (23)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). As-cast specimens	Average of 24-h periods	2	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). As-cast specimens	Average of 24-h periods	10	65 (150)	...	0.575 (23)	...	53
Haynes alloy No.188	R30188	...	...	10	Boiling	...	1.37 (54)	...	23
Haynes alloy No.25	R30605	...	Five 24-h test periods	10	Boiling	...	1.0 (40)	...	23
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	2	Room	24 h	Resistant	...	68

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	2	66 (150)	24 h	Resistant	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	2	Boiling	24 h	0.08 (3.0)	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	10	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	10	66 (150)	24 h	0.13 (5.0)	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	10	Boiling	24 h	1.04 (41)	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	20	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	20	66 (150)	24 h	0.53 (21)	...	68
Haynes alloy No.25	R30605	12-gage solution heat-treated sheet	Five 24-h test periods	20	Boiling	24 h	4.19 (165)	...	68
Haynes alloy No.556	R30556	...	...	10	Boiling	...	2.8 (110)	...	23
Multimet	R30155	12-gage solution heat-treated sheet	...	10	66 (150)	24 h	0.2 (8.0)	...	68
Multimet	R30155	12-gage solution heat-treated sheet	...	2	66 (150)	24 h	Resistant	...	68
Multimet	R30155	12-gage solution heat-treated sheet	...	2	Boiling	24-h	0.15 (6.0)	...	68
Multimet	R30155	12-gage solution heat-treated sheet	...	20	66 (150)	24 h	2.31 (91)	...	68
Multimet	R30155	12-gage solution heat-treated sheet	Five 24-h test periods	20	Boiling	24 h	25.4 (1000) min	...	68
Multimet	R30155	12-gage solution heat-treated sheet	Rate is for the fifth 24-h test period, not steady-state rate	10	Boiling	24 h	9.09 (358)	...	68
Ti-3Al-2.5V	...	...	...	10	Boiling	...	0.007 (0.3)	...	91
Ti-3Al-2.5V	...	...	...	30	Boiling	...	0.05 (2.1)	...	91
Ti-3Al-2.5V	...	...	...	50	Boiling	...	0.25 (10.1)	...	91
Titanium	...	...	...	10	Boiling	...	0.002 (0.1)	...	91
Titanium	...	...	...	10	Boiling	...	0.003 (0.12)	...	90
Titanium	...	...	...	15	24 (75)	...	0.006 (0.24)	...	90
Titanium	...	...	...	15	82 (180)	...	0.015 (0.6)	...	90
Titanium	...	...	...	30	Boiling	...	0.01 (0.4)	...	91
Titanium	...	...	...	50	24 (75)	...	0.013 (0.52)	...	90
Titanium	...	...	...	50	82 (180)	...	0.028 (1.12)	...	90
Titanium	...	...	...	50	Boiling	...	0.03 (1.4)	...	91
Titanium	...	...	Plus 5% HNO_3	5	21 (70)	...	0.003 (0.12) max	...	90
Titanium, grade 7	R52400	...	...	10	Boiling	...	Resistant	...	33
Titanium, grade 9	...	...	...	10	Boiling	...	0.008 (0.32)	...	33
Titanium, grade 9	...	...	...	30	Boiling	...	0.053 (2.12)	...	33
Titanium, grade 9	...	...	...	50	Boiling	...	0.26 (10.4)	...	33
Titanium, unalloyed	...	...	...	15	24 (75)	...	0.005 (0.2)	...	86
Titanium, unalloyed	...	...	...	15	82 (180)	...	0.015 (0.6)	...	86
Titanium, unalloyed	...	...	...	36.5	90 (195)	...	0.046 (1.8)	...	86

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Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium, unalloyed	...	...	...	50	24 (75)	...	0.013 (0.5)	...	86
Titanium, unalloyed	...	...	...	50	82 (180)	...	0.025 (1.0)	...	86
Titanium,unalloyed	...	...	...	10	Boiling	...	0.003 (0.12)	...	86
Zr702	R60702	...	...	10-50	Boiling	...	0.025 (1) max	...	15
Stainless steels									
12Cr	S41000	...	...	1	100 (212)	2 d	0.01 (0.4)	...	87
12Cr	S41000	...	...	15	100 (212)	2 d	0.860 (34)	...	87
18-8Mo	S31600	...	...	1	100 (212)	2 d	0.008 (0.3)	...	87
18-8Mo	S31600	...	...	15	100 (212)	2 d	2.57 (101)	...	87
18-8Ti	S32100	...	...	1	100 (212)	2 d	0.013 (0.5)	...	87
18-8Ti	S32100	...	...	15	100 (212)	2 d	5.84 (230)	...	87
27Cr	S44600	...	...	1	100 (212)	2 d	0.01 (0.4)	...	87
27Cr	S44600	...	...	15	100 (212)	2 d	0.97 (38)	...	87
301	S30100	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
301	S30100	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
301	S30100	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
301	S30100	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
301	S30100	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
301	S30100	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
302	S30200	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
302	S30200	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
302	S30200	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
302	S30200	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
302	S30200	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
302	S30200	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
303	S30300	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
303	S30300	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
303	S30300	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
303	S30300	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
303	S30300	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
303	S30300	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
303	S30300	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
303	S30300	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
303	S30300	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
303	S30300	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
303	S30300	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
303	S30300	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
304	S30400	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
304	S30400	...	...	10	82 (180)	3 d	0.15 (5.9)	...	87
304	S30400	...	...	15	100 (212)	2.5 d	2.49 (98)	...	87
304	S30400	...	...	15	82 (180)	3 d	1.42 (56)	...	87
304	S30400	...	...	25	24 (75)	3 d	Resistant	...	87
304	S30400	...	...	25	82 (180)	3 d	18.5 (730)	...	87
304	S30400	...	...	5	82 (180)	3 d	0.018 (0.7)	...	87
304	S30400	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
304	S30400	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
304	S30400	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
304	S30400	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
304	S30400	...	Chemically pure	10	21 (70)	...	Good	...	121
304	S30400	...	Chemically pure	50	21 (70)	...	Good	...	121
304L	S30403	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
304L	S30403	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
304L	S30403	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
304L	S30403	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
304L	S30403	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
304LN	S30453	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
304LN	S30453	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
304LN	S30453	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
304LN	S30453	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
304LN	S30453	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
316	S31600	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
316	S31600	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
316	S31600	...	...	10	82 (180)	3 d	0.305 (12)	...	87
316	S31600	...	...	15	100 (212)	2.5 d	9.96 (392)	...	87
316	S31600	...	...	15	82 (180)	3 d	0.460 (18)	...	87
316	S31600	...	...	25	24 (75)	3 d	0.018 (0.7)	...	87
316	S31600	...	...	25	82 (180)	3 d	27.4 (1080)	...	87
316	S31600	...	...	5	82 (180)	3 d	0.074 (2.9)	...	87
316	S31600	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
316	S31600	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
316	S31600	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
316	S31600	...	Chemically pure	10	21 (70)	...	Good	...	121
316	S31600	...	Chemically pure	50	21 (70)	...	Good	...	121
316F	S31620	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
316F	S31620	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
316F	S31620	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
316F	S31620	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
316F	S31620	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
316L	S31603	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
316L	S31603	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
316L	S31603	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
316L	S31603	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
316L	S31603	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
316LN	S31653	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
316LN	S31653	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
316LN	S31653	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
316LN	S31653	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
316LN	S31653	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
316Ti	S31635	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
316Ti	S31635	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
316Ti	S31635	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
316Ti	S31635	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
317L	S31703	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
317L	S31703	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
317L	S31703	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
317L	S31703	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
317L	S31703	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
317LN	S31725	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
317LN	S31725	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
317LN	S31725	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
317LN	S31725	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
321	S32100	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
321	S32100	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
321	S32100	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
321	S32100	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
321	S32100	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
321	S32100	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
329	S32900	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
329	S32900	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
329	S32900	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
329	S32900	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
329	S32900	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
329	S32900	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
347	S34700	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
347	S34700	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
347	S34700	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
347	S34700	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
347	S34700	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
347	S34700	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
403	S40300	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
403	S40300	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
403	S40300	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
403	S40300	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
403	S40300	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
403	S40300	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
405	S40500	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
405	S40500	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
405	S40500	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
405	S40500	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
405	S40500	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
405	S40500	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
409	S40900	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
409	S40900	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
409	S40900	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
409	S40900	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
409	S40900	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
409	S40900	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
410	S41000	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
410	S41000	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
410	S41000	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
410	S41000	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
410	S41000	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
410	S41000	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
410	S41000	...	Chemically pure	...	Room	...	Good	...	121
410	S41000	...	Chemically pure	10	21 (70)	...	Questionable	...	121
410	S41000	...	Chemically pure	50	21 (70)	...	Poor	...	121
416	S41600	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
416	S41600	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
416	S41600	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
416	S41600	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
416	S41600	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
416	S41600	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
420	S42000	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
420	S42000	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253
420	S42000	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
420	S42000	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
420	S42000	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
420	S42000	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
430	S43000	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
430	S43000	...	...	10% pure, free of SO_3	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Chromic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	50% pure, free of SO_3	20 (68)	...	Poor	...	253
430	S43000	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
430	S43000	...	...	50% tech. containing SO_3	20 (68)	...	Poor	...	253
430	S43000	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
430	S43000	...	Chemically pure	10	21 (70)	...	Good	...	121
430	S43000	...	Chemically pure	50	21 (70)	...	Poor	...	121
434	S43400	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
434	S43400	...	...	50% pure, free of SO_3	20 (68)	...	Questionable	...	253
434	S43400	...	...	50% pure, free of SO_3	Boiling	...	Poor	...	253
434	S43400	...	...	50% tech. containing SO_3	20 (68)	...	Questionable	...	253
434	S43400	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253
F51	S31803	...	...	10% pure, free of SO_3	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10% pure, free of SO_3	Boiling	...	Good	...	253
F51	S31803	...	...	50% pure, free of SO_3	20 (68)	...	Good	...	253
F51	S31803	...	...	50% pure, free of SO_3	Boiling	...	Questionable	...	253
F51	S31803	...	...	50% tech. containing SO_3	20 (68)	...	Good	...	253
F51	S31803	...	...	50% tech. containing SO_3	Boiling	...	Poor	...	253

Chromium Sulfate

Also known as chromic sulfate, $Cr_2(SO_4)_3$, is a violet or red powder that is insoluble in water and acids. The basic form (reduction of sodium dichromate) is used in tanning. Other uses are chrome plating, chromium alloys, mordant, catalyst, green paints and varnishes, green ink, and ceramic glazes.

Corrosion Behavior of Various Metals and Alloys in Chromium Sulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Chromium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253

Citric Acid

Citric acid, $(COOH)CH_2C(OH)(COOH)CH_2COOH$, also known as 2-hydroxy-1,2,3-propane tricarboxylic acid, is a colorless crystalline solid with a melting point of 153 °C (307 °F). Citric acid is soluble in water and alcohol. It is found in many plants, especially citrus fruits. The juice of unripe lemons is a commercial source of citric acid. The reaction of calcium citrate and dilute sulfuric acid yields citric acid and calcium sulfate, which may be separated by filtration. The food industry uses citric acid as a flavoring agent and as an antioxidant. Citric acid, formulated with propylene glycol and butylated hydroxy anisol, is used as a stabilizer for fats, greases, and tallow. Etching, textile dyeing, and printing operations use citric acid in various applications, and it is also used to adjust the pH in certain electroplating baths.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 exhibits good resistance to citric acid at ambient temperature. In laboratory tests, higher concentrations of the citric acid solution had little effect on the corrosion rate, but an increase in temperature raised it substantially. The corrosion rate also increased in the presence of chlorides of heavy metals. Aluminum alloy 356.0 valves have been used to service citrus acid solutions. Fermenting vats, crystallizers, pipes, and other equipment made of aluminum have been used in manufacturing citric acid, because aluminum has no harmful effect on the organisms involved.

Stainless Steel. Type 316 stainless steel has been recommended for all concentrations of citric acid up to the boiling point, whereas type 304 has been used at moderate temperatures.

Zirconium. Zirconium resists corrosion in citric acid.

Corrosion Behavior of Various Metals and Alloys in Citric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum									
Aluminum-maganese alloys	...	...	Solution	...	20-100 (68-212)	...	Resistant	...	92
Carbon and alloy steels									
16Ni, 8Cr, 5Si, 1Cu	...	...	...	40	80	96 h	0.36 (14.2)	...	206
16Ni, 8Cr, 5Si, 1Cu, 1Mo	...	...	...	...	...	96 h	0.12 (4.9)	...	206

(Continued)

Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn.	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn.	C52000	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Gold	P00016	...	...	20	Boiling	...	0.05 (2) max	...	8
Gold	P00016	...	...	30	Boiling	...	0.05 (2) max	...	8
Lead	L50045	...	...	10	Boiling	...	0.025 (1.0)	...	2
Silver	P07010	...	...	0-30	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	0-30	Boiling	...	0.05 (2) max	...	4
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	Nonaerated solutions	...	20 (68)	...	Resistant	...	94
Tin	...	...	Nonaerated solutions	...	20 (68)	...	Resistant	...	94
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84mm (0.112in.) thick	Solutions were prepared with reagent-grade chemicals	7	80 (176)	7 d	Resistant	No pitting occurred	44
Inconel 601	N06601	...	...	10	80 (176)	7 d	0.002 (0.1) max	...	64
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Nickel 200	N02200	...	Lab aerated test	2	82 (180)	...	0.85 (180)	...	44
Nickel 200	N02200	...	Lab aerated test	5	30 (86)	...	0.375 (15)	...	44
Nickel 200	N02200	...	Lab immersion test	2	71 (160)	...	0.14 (5.5)	...	44
Nickel 200	N02200	...	Lab immersion test	2	Room	...	0.02 (0.8)	...	44
Nickel 200	N02200	...	Lab immersion test	5	30 (86)	...	0.125 (5)	...	44
Nickel 200	N02200	...	Lab immersion test	5	60 (140)	...	0.5 (20)	...	44
Nickel 200	N02200	...	Lab immersion test	58	Boiling	...	0.425 (17)	...	44
Refractory metals and alloys									
Ti-3Al-2.5V	...	...	...	50	Boiling	...	0.37 (15)	...	91
Titanium	...	...	...	10	100 (212)	...	0.009 (0.36)	...	90
Titanium	...	...	...	25	100 (212)	...	0.001 (0.04)	...	90

(Continued)

Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	...	50	60 (140)	...	0.000 (0.000)	...	90
Titanium	...	...	...	50	Boiling	...	0.35 (14)	...	91
Titanium	...	...	...	50	Boiling	...	1.27 (50.8) max	...	90
Titanium	...	...	...	672	149 (301)	...	Poor	...	90
Titanium	...	...	Aerated	50	100 (212)	...	0.127 (5.08) max	...	90
Titanium, grade 12	R53400	...	...	50	Boiling	...	0.013 (0.52)	...	33
Titanium, grade 7	R52400	...	...	50	Boiling	...	0.025 (1)	...	33
Titanium, grade 9	...	...	...	50	Boiling	...	0.38 (15.2)	...	33
Titanium, unalloyed	...	...	...	50	60 (140)	...	.005 (0.2) max	...	218
Zr702	R60702	...	...	10	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	10-50	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	25	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	50	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	50	Boiling	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	1	20 (68)	...	Resistant	...	253
301	S30100	...	...	1	Boiling	...	Resistant	...	253
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
301	S30100	...	...	25	20 (68)	...	Resistant	...	253
301	S30100	...	...	25	Boiling	...	Questionable	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Questionable	...	253
301	S30100	...	3 bar	5%	140 (284)	...	Good	...	253
302	S30200	...	...	1	20 (68)	...	Resistant	...	253
302	S30200	...	...	1	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Questionable	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Questionable	...	253
302	S30200	...	3 bar	5%	140 (284)	...	Good	...	253
303	S30300	...	...	1	20 (68)	...	Resistant	...	253
303	S30300	...	...	1	20 (68)	...	Resistant	...	253
303	S30300	...	...	1	Boiling	...	Good	...	253
303	S30300	...	...	1	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Good	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Poor	...	253
303	S30300	...	...	25	Boiling	...	Questionable	...	253
303	S30300	...	...	50	20 (68)	...	Good	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Poor	...	253
303	S30300	...	...	50	Boiling	...	Questionable	...	253
303	S30300	...	3 bar	5%	140 (284)	...	Good	...	253
303	S30300	...	3 bar	5%	140 (284)	...	Good	...	253
304	S30400	...	...	1	20 (68)	...	Resistant	...	253
304	S30400	...	...	1	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	10	99-102 (210-215)	...	0.210 (8.3)	...	87
304	S30400	...	...	10	Boiling	...	Good	...	121
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	20	Boiling	24 h	0.01 (0.4)	...	52
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Questionable	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	21 (70)	...	Good	...	121
304	S30400	...	...	50	Boiling	...	Poor	...	121
304	S30400	...	...	50	Boiling	...	Questionable	...	253
304	S30400	...	3 bar	5%	140 (284)	...	Good	...	253
304L	S30403	...	...	1	20 (68)	...	Resistant	...	253
304L	S30403	...	...	1	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Questionable	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Questionable	...	253
304L	S30403	...	3 bar	5%	140 (284)	...	Good	...	253
304LN	S30453	...	...	1	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	1	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Questionable	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Questionable	...	253
304LN	S30453	...	3 bar	5%	140 (284)	...	Good	...	253
316	S31600	...	...	1	20 (68)	...	Resistant	...	253
316	S31600	...	...	1	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	10	99-102 (210-215)	...	0.013 (0.5)	...	87
316	S31600	...	...	10	Boiling	...	Good	...	121
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	20	Boiling	24 h	0.0125 (0.5)	...	52
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	21 (70)	...	Good	...	121
316	S31600	...	...	50	Boiling	...	Good	...	121
316	S31600	...	...	50	Boiling	...	Good	...	253
316	S31600	...	3 bar	5%	140 (284)	...	Resistant	...	253
316F	S31620	...	...	1	20 (68)	...	Resistant	...	253
316F	S31620	...	...	1	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Questionable	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	...	50	Boiling	...	Questionable	...	253
316F	S31620	...	3 bar	5%	140 (284)	...	Good	...	253
316L	S31603	...	...	1	20 (68)	...	Resistant	...	253
316L	S31603	...	...	1	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Good	...	253
316L	S31603	...	3 bar	5%	140 (284)	...	Resistant	...	253
316LN	S31653	...	...	1	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	1	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Good	...	253
316LN	S31653	...	3 bar	5%	140 (284)	...	Resistant	...	253
316Ti	S31635	...	...	1	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	1	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Good	...	253
316Ti	S31635	...	3 bar	5%	140 (284)	...	Resistant	...	253
317L	S31703	...	...	1	20 (68)	...	Resistant	...	253
317L	S31703	...	...	1	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Good	...	253
317L	S31703	...	3 bar	5%	140 (284)	...	Resistant	...	253
317LN	S31725	...	...	1	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	1	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Good	...	253
317LN	S31725	...	3 bar	5%	140 (284)	...	Resistant	...	253
321	S32100	...	...	1	20 (68)	...	Resistant	...	253
321	S32100	...	...	1	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Questionable	...	253
321	S32100	...	3 bar	5%	140 (284)	...	Good	...	253
329	S32900	...	...	1	20 (68)	...	Resistant	...	253
329	S32900	...	...	1	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Good	...	253
329	S32900	...	3 bar	5%	140 (284)	...	Resistant	...	253
347	S34700	...	...	1	20 (68)	...	Resistant	...	253
347	S34700	...	...	1	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Questionable	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Questionable	...	253
347	S34700	...	3 bar	5%	140 (284)	...	Good	...	253
403	S40300	...	...	1	20 (68)	...	Good	...	253
403	S40300	...	...	1	Boiling	...	Questionable	...	253
403	S40300	...	...	10	20 (68)	...	Questionable	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	...	25	20 (68)	...	Questionable	...	253
403	S40300	...	...	25	Boiling	...	Poor	...	253
403	S40300	...	...	50	20 (68)	...	Questionable	...	253
403	S40300	...	...	50	Boiling	...	Poor	...	253
403	S40300	...	3 bar	5%	140 (284)	...	Questionable	...	253
405	S40500	...	...	1	20 (68)	...	Good	...	253
405	S40500	...	...	1	Boiling	...	Questionable	...	253
405	S40500	...	...	10	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	...	25	20 (68)	...	Questionable	...	253
405	S40500	...	...	25	Boiling	...	Poor	...	253
405	S40500	...	...	50	20 (68)	...	Questionable	...	253
405	S40500	...	...	50	Boiling	...	Poor	...	253
405	S40500	...	3 bar	5%	140 (284)	...	Questionable	...	253
409	S40900	...	...	1	20 (68)	...	Good	...	253
409	S40900	...	...	1	Boiling	...	Questionable	...	253
409	S40900	...	...	10	20 (68)	...	Questionable	...	253
409	S40900	...	...	10	Boiling	...	0.0025 (0.1)	...	87
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	...	10	Room	...	0.00 (0.00)	...	87
409	S40900	...	...	25	20 (68)	...	Questionable	...	253
409	S40900	...	...	25	Boiling	...	Poor	...	253
409	S40900	...	...	50	20 (68)	...	Questionable	...	253
409	S40900	...	...	50	Boiling	...	Poor	...	253
409	S40900	...	...	6	Boiling	...	0.0025 (0.1)	...	87
409	S40900	...	...	6	Room	...	0.00 (0.00)	...	87
409	S40900	...	3 bar	5%	140 (284)	...	Questionable	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	1	20 (68)	...	Good	...	253

(Continued)

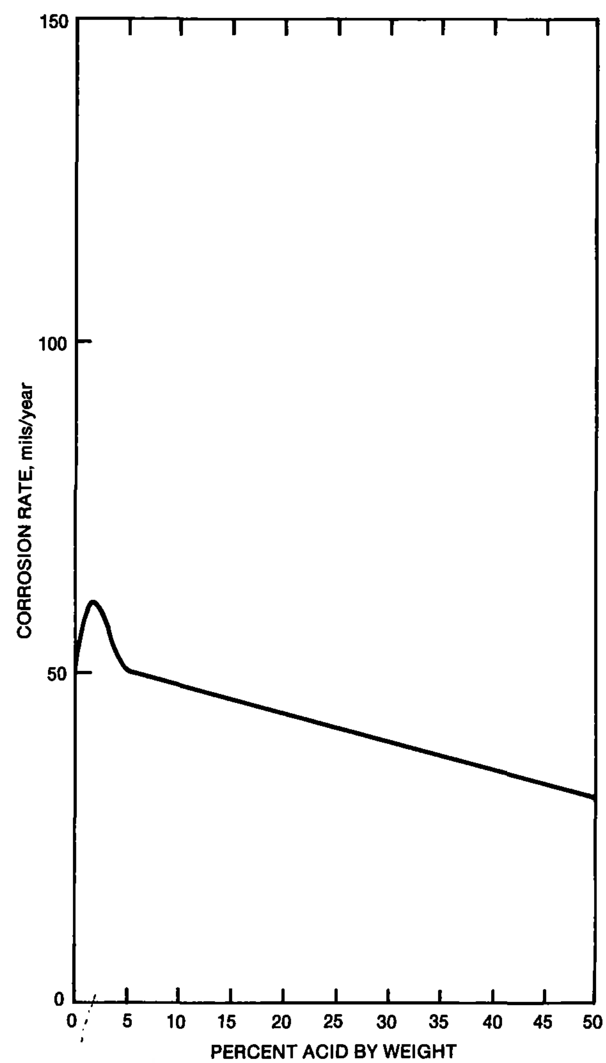
Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	1	Boiling	...	Questionable	...	253
410	S41000	...	...	10	20 (68)	...	Questionable	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	10	99-102 (210-215)	...	0.260 (10.3)	...	87
410	S41000	...	...	10	Boiling	...	Poor	...	121
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	...	25	20 (68)	...	Questionable	...	253
410	S41000	...	...	25	Boiling	...	Poor	...	253
410	S41000	...	...	50	20 (68)	...	Questionable	...	253
410	S41000	...	...	50	21 (70)	...	Questionable	...	121
410	S41000	...	...	50	Boiling	...	Poor	...	121
410	S41000	...	...	50	Boiling	...	Poor	...	253
410	S41000	...	3 bar	5%	140 (284)	...	Questionable	...	253
410	S41000	...	Plus 10% potassium ferricyanide	...	Room	...	Resistant	...	121
416	S41600	...	...	1	20 (68)	...	Good	...	253
416	S41600	...	...	1	Boiling	...	Questionable	...	253
416	S41600	...	...	10	20 (68)	...	Questionable	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	...	25	20 (68)	...	Questionable	...	253
416	S41600	...	...	25	Boiling	...	Poor	...	253
416	S41600	...	...	50	20 (68)	...	Questionable	...	253
416	S41600	...	...	50	Boiling	...	Poor	...	253
416	S41600	...	3 bar	5%	140 (284)	...	Questionable	...	253
420	S42000	...	...	1	20 (68)	...	Good	...	253
420	S42000	...	...	1	Boiling	...	Questionable	...	253
420	S42000	...	...	10	20 (68)	...	Questionable	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	...	25	20 (68)	...	Questionable	...	253
420	S42000	...	...	25	Boiling	...	Poor	...	253
420	S42000	...	...	50	20 (68)	...	Questionable	...	253
420	S42000	...	...	50	Boiling	...	Poor	...	253
420	S42000	...	3 bar	5%	140 (284)	...	Questionable	...	253
430	S43000	...	...	1	20 (68)	...	Resistant	...	253
430	S43000	...	...	1	Boiling	...	Good	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	99-102 (210-215)	...	0.020 (0.8)	...	87
430	S43000	...	...	10	Boiling	...	Questionable	...	121
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	25	20 (68)	...	Good	...	253
430	S43000	...	...	25	Boiling	...	Poor	...	253
430	S43000	...	...	50	20 (68)	...	Good	...	253
430	S43000	...	...	50	21 (70)	...	Good	...	121
430	S43000	...	...	50	Boiling	...	Poor	...	121
430	S43000	...	...	50	Boiling	...	Poor	...	253
430	S43000	...	3 bar	5%	140 (284)	...	Good	...	253
434	S43400	...	...	1	20 (68)	...	Resistant	...	253
434	S43400	...	...	1	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	25	20 (68)	...	Resistant	...	253
434	S43400	...	...	25	Boiling	....	Questionable	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Citric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	50	Boiling	...	Questionable	...	253
434	S43400	...	3 bar	5%	140 (284)	...	Good	...	253
444	S44400	...	...	20	Boiling	24 h	0.0075 (0.3)	...	52
F51	S31803	...	...	1	20 (68)	...	Resistant	...	253
F51	S31803	...	...	1	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253
F51	S31803	...	...	25	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Good	...	253
F51	S31803	...	3 bar	5%	140 (284)	...	Resistant	...	253
Ferralium 255	S32550	...	Plus 8% NaCl	5	141 (286)	...	0.01 (0.1) max	...	60



LIVE GRAPH
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Aluminum. Effect of citric acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 25.

Concrete

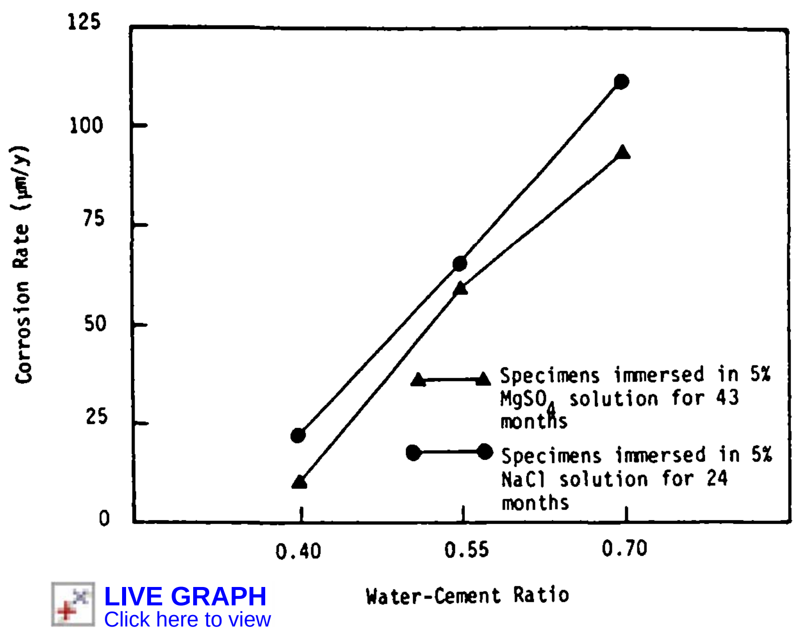
Concrete is a mixture of fine and coarse aggregates firmly bound into a monolithic mass by a cementing agent. The cement ordinarily employed for concrete is the standard Portland cement. The aggregates are usually sand and crushed stone or gravel. Crushed slag or cinders are used in special kinds of concrete. The formation of concrete can be thought of as a process in which the voids between the particles of coarse aggregate are filled by the fine aggregate, and the whole is cemented together by the binding action of the cement.

Due to its strength, permanency, and relatively low cost, concrete is one of the most important building materials employed in modern construction. It is widely used for foundations of all types, buildings, bridges, dams, retaining walls, highways, and other purposes too numerous to mention. However, the success of concrete in meeting any particular set of conditions depends upon the proper correlation of many factors bearing on the selection and mixing of the materials, the placing of the concrete, and the original design.

Calcium chloride is often added to mortar and concrete to accelerate curing and to develop high early strength. Sodium chloride may also be present as a contaminant of the water and sand. These chlorides and the presence of sulfates in the cement, can cause serious corrosion of steel.

Aluminum. While aluminum alloys perform well in many applications involving mortar and concrete, definite benefits may be obtained by using protective coatings to prevent staining, eliminate crevice corrosion, minimize galvanic corrosion, and improve adhesion by decreasing gas evolution at the metal interface. In lab tests, the addition of appreciable amounts of either calcium chloride or sodium chloride to concrete had little effect on the corrosivity of the concrete to aluminum alloys.

Carbon Steel. The presence of chloride ions appears to be the principal cause of steel corrosion in concrete.



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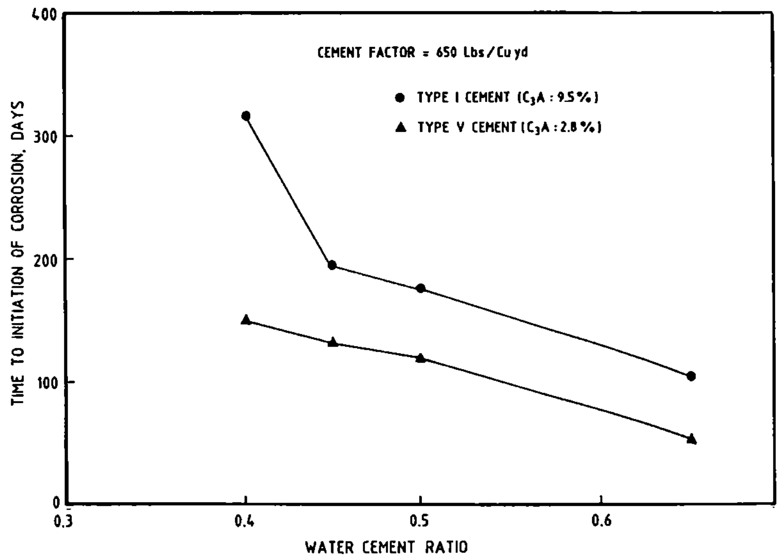
Reinforcing steel. Average corrosion rate values of steel reinforced concrete specimens immersed in 5% $MgSo_4$ and 5% NaCl solutions. Ref. 264



LIVE GRAPH
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Reinforcing steel. Effect of cement type on corrosion of reinforcing steel in concrete prism made with different water/cement ratios. Ref. 273

Copals

Copal is the general name for fossil and other hard resins found in almost all tropical countries. All are distinguished by their yellowish to yellowish-brown color and their solubility in chloral hydrate, alcohol, linseed oil, and turpentine. Their main use is in the manufacture of lacquers, varnishes, coatings, and adhesives.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Varnishes made from copal resins have been produced in aluminum alloy equipment.

Corrosion Behavior of Various Metals and Alloys in Copals

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Silver	P07010	...	Pure and wet	...	400 (750)	...	0.05 (2) max	...	10
Stainless steels									
410	S41000	...	Varnish	...	Room	...	Resistant	...	121

Copper Carbonate

Copper carbonate (basic), $CuCO_3 \cdot Cu(OH)_2$, dark green monoclinic crystals, insoluble in cold H_2O, decomposes in H_2O, soluble in potassium cyanide. Malachite, copper ore, is of this composition. Refined compound is used as a pigment.

Corrosion Behavior of Various Metals and Alloys in Copper Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Creosote and Creosote Oil

Creosote is an oily liquid with a burning taste, obtained by distilling coal and wood tar; used as an antiseptic and wood preservative.

Creosote oil is a yellow-to-green oily liquid that boils between 240 and 270 °C, is immiscible with water and soluble in alcohol, and is derived by the fractional distillation of coal tar; used as a wood preservative, fungicide and disinfectant. Also, coal-tar creosote.

Corrosion Behavior of Various Metals and Alloys in Creosote

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Good	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Good	...	253
403	S40300	...	...	...	Boiling	...	Questionable	...	253
405	S40500	...	...	...	20 (68)	...	Good	...	253
405	S40500	...	...	...	Boiling	...	Questionable	...	253
409	S40900	...	...	...	20 (68)	...	Good	...	253
409	S40900	...	...	...	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Creosote (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	...	20 (68)	...	Good	...	253
410	S41000	...	...	...	Boiling	...	Questionable	...	253
416	S41600	...	...	...	20 (68)	...	Good	...	253
416	S41600	...	...	...	Boiling	...	Questionable	...	253
420	S42000	...	...	...	20 (68)	...	Good	...	253
420	S42000	...	...	...	Boiling	...	Questionable	...	253
430	S43000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	...	Boiling	...	Good	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	..	Boiling	...	Resistant	...	253
F51	S31803	...	...		20 (68)	...	Resistant	...	253
F51	S31803	...	...		Boiling	...	Resistant	...	253

Cresol

Cresol, $CH_3C_6H_4OH$, also known as cresylic acid, methyl phenol, and tricresol, is a mixture of three isomers of cresol derived from coal tar and is used in making plastics, ore flotation, refining petroleum, and as a strong antiseptic. Orthocresol is a colorless solid with a melting point of 30 °C (86 °F) that is soluble in alcohol, but only slightly soluble in water. It is used in making disinfectants and as a plasticizer. Metacresol is a colorless liquid used in the manufacture of photographic developers, printing inks, and paint removers. It is also used as a leather preservative. The least soluble isomer, paracresol, is a colorless solid and is used in the production of dyes and pharmaceuticals.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 had excellent resistance to 1, 3, and 100% solutions of cresol at ambient temperature. In other laboratory tests, cresol was very corrosive to aluminum alloy 1100 at the boiling point.

Corrosion Behavior of Various Metals and Alloys in Cresol

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	7
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cresol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Tin	...	...	...	50	100 (212)	...	Poor	...	94
Tin	...	...	...	50	20 (68)	...	Resistant	...	94
Tin	...	...	...	50	60 (140)	...	Poor	...	94
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	Chemical processing; lab test; no aeration; no agitation. *p*- and *m*- cresol mixture, technical (alternately immersed)	...	Room	11 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; lab test; no aeration; no agitation. *p*- and *m*- cresol mixture, technical (alternately immersed)	...	71 (160)	11 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Cupric Acetate

Cupric acetate, $Cu(C_2H_3O_2)_2 \cdot H_2O$, is a dark brown powder that melts at 115 °C, decomposes at 240 °C; is slightly soluble in cold H_2O and alcohol, and moderately soluble in hot H_2O and ether. Used as a fungicide, insecticide, as a catalyst, and in pigments.

Corrosion Behavior of Various Metals and Alloys in Cupric Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Cupric Chloride

Cupric chloride, $CuCl_2$, also known as copper chloride, is a yellowish-brown solid that is soluble in water and alcohol. The dihydrate of cupric chloride, $CuCl_2{\cdot}H_2O$, is a green crystalline solid that is soluble in water. Cupric chloride is used in the textile industry as a mordant in the dyeing and printing of fabrics. It is also used in refining gold, silver, and copper.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Titanium. Cupric chloride, a halide salt of an oxidizing cationic species, enhances the passivity of titanium alloys to the extent that corrosion rates are negligible.

Zirconium. Zirconium is highly resistant to corrosion by most saline solutions, but cupric chloride is an exception. Cupric chloride attacks zirconium and causes stress-corrosion cracking of zirconium alloys.

Corrosion Behavior of Various Metals and Alloys in Cupric Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Coppers and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
Lead	L50045	...	...	10-40	24 (75)	...	1.3 (50) min	...	95
Palladium	P03980	...	...	100 g/L	Room	...	0.25 (10) max	...	17
Platinum	P04995	...	...	100 g/L	Room	...	Resistant	...	5
Silver	P07010	...	...	All	100 (212)	...	Poor	...	9
Refractory metals and alloys									
44Co-31Cr-13W	...	As-cast specimens	Average of five 24-h periods	10	Room	...	0.013 (0.5)	...	53
44Co-31Cr-13W	...	As-cast specimens	Average of five 24-h periods	10	Room		0.012 (0.5)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled. As-cast specimens	...	10	Room	...	0.05 (2)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled. As-cast specimens	Average of five 24-h periods	10	Room	...	0.05 (2)	...	53
50Co-20Cr-15W-10Ni	...	...	...	10	Room	...	0.005 (0.2)	...	53
50Co-20Cr-15W-10Ni	...	As-cast specimens	Average of five 24-h periods	10	Room	...	0.005 (0.2)	...	53

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
53Co-30Cr-4.5W	...	As-cast specimens	Average of five 24-h periods	10	Room	...	0.012 (0.5)	...	53
53Co-30Cr-4.5W	...	As-cast specimens	Average of five 24-h periods	10	Room	...	0.012 (0.5)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). As-cast specimens	Average of five 24-h periods	10	Room	...	0.05 (2)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled. As-cast specimens	Average of five 24-h periods	10	Room	...	0.05 (2)	...	53
Haynes alloy No. 25	R30605	...	...	10	Room	...	0.01 (0.2) max	...	124
Haynes alloy No. 25	R30605	...	...	2	Room	...	Resistant	...	124
Haynes alloy No. 25	R30605	...	Plus 10% NaCl	10	66 (150)	...	Resistant	...	124
Haynes alloy No. 25	R30605	...	Plus 10% NaCl	5	66 (150)	...	Resistant	...	124
Haynes alloy No. 25	R30605	...	Plus 10% NaCl	5	Boiling	...	0.02 (0.5) max	...	124
Haynes alloy No. 25	R30605	...	Plus 5% NaCl	2	66 (150)	...	Resistant	...	124
Haynes alloy No. 25	R30605	...	Plus 5% NaCl	2	Boiling	...	0.01 (0.1) max	...	124
Multimet	R30155	...	...	10	Room	...	Resistant	...	124
Multimet	R30155	...	...	2	Room	...	Resistant	...	124
Multimet	R30155	...	Plus 10% NaCl	10	66 (150)	...	Resistant	...	124
Multimet	R30155	...	Plus 10% NaCl	5	66 (150)	...	Resistant	...	124
Multimet	R30155	...	Plus 10% NaCl	5	Boiling	...	25.4 (1000) min	...	124
Multimet	R30155	...	Plus 5% NaCl	2	66 (150)	...	4.06 (160)	...	124
Multimet	R30155	...	Plus 5% NaCl	2	Boiling	...	23.3 (919)	...	124
Titanium	...	...	...	20	Boiling	...	Resistant	...	90
Titanium	...	...	...	40	Boiling	...	0.005 (0.2)	...	90
Titanium	...	...	...	50	90 (194)	...	0.003 (0.12) max	...	90
Titanium	...	...	...	55	118 (244)	...	0.003 (0.12)	...	90
Zr702	R60702	...	...	10	35-100 (95-212)	...	1.3 (50) min	...	15
Zr702	R60702	...	...	20	35-100 (95-212)	...	1.3 (50) min	...	15
Zr702	R60702	...	...	20	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	...	40	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	...	5	35-100 (95-212)	...	1.3 (50) min	...	15
Zr702	R60702	...	...	50	Boiling	...	1.3 (50) min	...	15
Zr704	R60704	...	...	10	35-100 (95-212)	...	1.3 (50) min	...	15
Zr704	R60704	...	...	20	35-100 (95-212)	...	1.3 (50) min	...	15
Zr704	R60704	...	...	20	Boiling	...	1.3 (50) min	...	15
Zr704	R60704	...	...	40	Boiling	...	1.3 (50) min	...	15
Zr704	R60704	...	...	5	35-100 (95-212)	...	1.3 (50) min	...	15
Zr704	R60704	...	...	50	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	...	10	35-100 (95-212)	...	1.3 (50) min	...	15
Zr705	R60705	...	...	20	35-100 (95-212)	...	1.3 (50) min	...	15
Zr705	R60705	...	...	20	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	...	40	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	...	5	35-100 (95-212)	...	1.3 (50) min	...	15
Zr705	R60705	...	...	50	Boiling	...	1.3 (50) min	...	15
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	Saturated	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	Saturated	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	10	21 (70)	...	Poor	...	121
304	S30400	...	...	Saturated	20 (68)	...	Poor	Pitting	253
304	S30400	...	Petroleum processing; field or pilot plant test; slight to moderate aeration. Plus cupric sulfate and sodium chloride	...	16-27 (60-80)	233 d	0.003 (0.1) max	Severe pitting Crevice attack	89
304	S30400	...	Research (electrolysis) lab test	10	...	1 d	4.4 (174)	Severe pitting	89
304L	S30403	...	...	Saturated	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	Saturated	20 (68)	...	Poor	Pitting	253
316	S31600	...	...	10	21 (70)	...	Poor	...	121
316	S31600	...	...	Saturated	20 (68)	...	Poor	Pitting	253
316	S31600	...	Automotive; lab test; no aeration; no agitation. Cuprous chloride, ammonia, magnesium oxide (carbon-monoxide absorption chamber)	...	Room	1 d	(1.4) 57	Severe pitting	89
316	S31600	...	Jewelry; lab test	10	102 (215)	2 d	50 (2100)	...	89
316	S31600	...	Petroleum processing; field or pilot plant test; slight to moderate aeration. Plus cupric sulfate and sodium chloride	...	16-27 (60-80)	233 d	0.003 (0.1) max	Moderate pitting	89
316F	S31620	...	...	Saturated	20 (68)	...	Poor	Pitting	253
316L	S31603	...	...	Saturated	20 (68)	...	Poor	Pitting	253
316LN	S31653	...	...	Saturated	20 (68)	...	Poor	Pitting	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Poor	Pitting	253
317	S31700	...	Chemical processing; lab test; no aeration; no agitation. Plus sodium chloride 226.7 g per 2345.9 ml, pressure 6 in. of mercury	7.66	26-27 (78-80)	7 d	0.04 (1.7)	...	89
317	S31700	...	Chemical processing; lab test; strong aeration; no agitation. Plus sodium chloride 226.7 g per 2345.9 ml, pressure 6 in. of mercury	7.66	26-27 (78-80)	7 d	0.005 (0.2)	...	89
317L	S31703	...	...	Saturated	20 (68)	...	Poor	Pitting	253
317LN	S31725	...	...	Saturated	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	Saturated	20 (68)	...	Poor	Pitting	253
329	S32900	...	...	Saturated	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	Saturated	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	Saturated	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	Saturated	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	Saturated	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	10	21 (70)	...	Poor	...	121
410	S41000	...	...	Saturated	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	Saturated	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	Saturated	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	10	21 (70)	...	Poor	...	121
430	S43000	...	...	Saturated	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	Saturated	20 (68)	...	Poor	Pitting	253
F51	S31803	...	...	Saturated	20 (68)	...	Poor	Pitting	253

Cupric Nitrate

Cupric nitrate, $Cu(NO_3)_2 \cdot 3H_2O$, also known as copper nitrate, is a blue, deliquescent, crystalline solid that is soluble in water. Cupric nitrate is used in electroplating copper on iron.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Wires of copper alloy Cu-23Zn-12Ni used in telephone equipment under the conditions of a 6-g load and a positive potential were observed to undergo stress-corrosion cracking within 2 years. Laboratory tests implied that nitrate salts were the cause. The same results were achieved in the laboratory using high humidity, a constant load of 386 MPa, and a potential applied so that the wires were anodic to the normal corrosion potential. Cracking was observed when the surface had a high nitrate concentration even without an applied potential. Wires made of Cu-20Ni resisted cracking under the same conditions.

Corrosion Behavior of Various Metals and Alloys in Cupric Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Coppers and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	9
Refractory metals and alloys									
Hafnium	...	...	...	40	...	10 d	Resistant	...	11
Hafnium	...	...	...	40	...	10 d	Resistant	...	11
Niobium	R04210	...	...	40	Boiling	...	Resistant	...	2
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Nitrate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
403	S40300	...	...	50	20 (68)	...	Resistant	...	253
403	S40300	...	...	50	Boiling	...	Resistant	...	253
405	S40500	...	...	50	20 (68)	...	Resistant	...	253
405	S40500	...	...	50	Boiling	...	Resistant	...	253
409	S40900	...	...	50	20 (68)	...	Resistant	...	253
409	S40900	...	...	50	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	50	20 (68)	...	Resistant	...	253
410	S41000	...	...	50	Boiling	...	Resistant	...	253
416	S41600	...	...	50	20 (68)	...	Resistant	...	253
416	S41600	...	...	50	Boiling	...	Resistant	...	253
420	S42000	...	...	50	20 (68)	...	Resistant	...	253
420	S42000	...	...	50	Boiling	...	Resistant	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	50	20 (68)	...	Resistant	...	253
430	S43000	...	...	50	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253

Cupric Sulfate

Cupric sulfate, $CuSO_4$, also known as hydrocyanite and copper sulfate, is a greenish-white salt with a melting point of 200 °C (392 °F). It is soluble in water and used in copper-plating baths, dyestuffs, and germicides. Cupric sulfate (hydrated), $CuSO_4 \cdot 5H_2O$, also known as blue vitriol, chalcanthite, and bluestone, is an azure blue material used in the leather industry. It is prepared by the reaction of sulfuric acid and copper. It is also obtained as a by-product from copper refineries.

Corrosion Behavior of Various Metals and Alloys in Cupric Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Iridium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Palladium	P03980	...	...	100 g/L	100 (212)	...	Resistant	...	17
Platinum	P04995	...	...	100 g/L	100 (212)	...	Resistant	...	5
Rhodium	P05990	...	...	100 g/L	100 (212)	...	Resistant	...	29
Silver	P07010	...	...	All	Room-boiling	...	0.05 (2) max	...	9
Silver	P07010	...	In NaCl	...	100 (212)	...	Poor	...	9
Nickel and alloys									
Alloy 825	N08825	...	Metal processing (plating); field or pilot plant test; strong aeration; rapid agitation. Plus 10% sulfuric acid, 9-10 g/L manganese dioxide	~5	70 (158)	63 d	0.003 (0.1) max	...	89
Incoloy 800	N08800	Test specimens were cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	10	80 (176)	7 d	Resistant	No pitting	44
Inconel 601	N06601	...	...	10	80 (176)	7 d	Resistant	...	64

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Titanium	...	...	...	50	Boiling	...	Resistant	...	90
Titanium	...	...	Plus 2% H_2SO_4	Saturated.	Room	...	0.018 (0.72)	...	90
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	10	Boiling	...	Resistant	...	121
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	Metal processing (plating); field or pilot plant test; strong aeration; rapid agitation. Plus 10% sulfuric acid, 9-10 g/L manganese dioxide	~5	70 (158)	63 d	0.003 (0.1) max	...	89
304	S30400	...	Metal processing; field or pilot plant test; no aeration; no agitation. Plus copper-refinery electrolyte, 200-235 g/L sulfuric acid, 20-22 g/L nickel ion as sulfate, pressure	~8-10	65 (150)	32.9 d	0.003 (0.1) max	...	89
304	S30400	...	Metal processing; field or pilot plant test, no aeration; rapid agitation. Plus 0.4-0.8% sulfuric acid (evaporator). Saturated	~65	76-104 (170-220)	30 d	0.005 (0.2)	...	89
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	10	Boiling	...	Resistant	...	121
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Metal processing (plating); field or pilot plant test; strong aeration; rapid agitation. Plus 10% sulfuric acid, 9-10 g/L manganese dioxide	~5	70 (158)	63 d	0.003 (0.1) max	...	89
316	S31600	...	Metal processing; field or pilot plant test; no aeration; no agitaiton. Plus copper-refinery electrolyte, 200-235 g/L sulfuric acid, 20-22 g/L nickel ion as sulfate, pressure	~8-10	65 (150)	32.9 d	0.003 (0.1) max	...	89
316	S31600	...	Metal processing; field or pilot plant test; no aeration; rapid agitation. Plus 0.4-0.8% sulfuric acid (evaporator.) Saturated	~65	76-104 (170-220)	30 d	0.005 (0.2)	...	89
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317	S31700	...	Metal processing (plating); field or pilot plant test; strong aeration; rapid agitation. Plus 10% sulfuric acid, 9-10 g/L manganese dioxide	~5	70 (158)	63 d	0.003 (0.1) max	...	89
317	S31700	...	Metal processing; field or pilot plant test; no aeration; rapid agitation. Plus 0.4-0.8% sulfuric acid (evaporator). Saturated	~65	76-104 (170-220)	30 d	0.003 0.1	...	89
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Cupric Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	Boiling	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	Boiling	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	Boiling	...	Resistant	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	10	Boiling	...	Questionable	...	121
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	Boiling	...	Resistant	...	253
410	S41000	...	Plus 2% H_2SO_4	...	Room	...	Resistant	...	121
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	Boiling	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	Boiling	...	Resistant	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	Boiling	...	Good	...	121
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
430	S43000	Nonsensitized. Heat treated at 760°C (1400°F) 1 h, water quenched	Plus Cu, 50% H_2SO_4	...	...	...	2.1 (84)	Intergranular corrosion	41
430	S43000	Sensitized. Heat treated at 1093°C (2000°F) 1 h, air cooled	Plus Cu, 50% H_2SO_4	...	...	...	118.2 (4728)	Intergranular corrosion	41
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
Carpenter 20	...	...	Metal processing (plating); field or pilot plant test; strong aeration; rapid agitation. Plus 10% sulfuric acid, 9-10 g/L manganese dioxide	~5	70 (158)	63 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Metal processing; field or pilot plant test; no aeration; no agitation. Plus copper-refinery electrolyte, 200-235 g/L sulfuric acid, 20-22 g/L nickel ion as sulfate, pressure	~8-10	65 (150)	32.9 d	0.003 (0.1) max	...	89
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Susceptibility of Naval Brass to Stress-Corrosion Cracking in 0.1M Cupric Sulfate

Environment	*Test potential* (mV(SCE))	*Strain ϵ_F to failure* (%)	*Reduction in area* (%)	*Strain ϵ_l at maximum load* (%)	*Ultimate tensile strength* (MPa)
0.1 M $CuSO_4$	45 (corrosion potential)	14	12	13	330
0.1 M $CuSO_4$	300	11	9	11	320
0.1 M $CuSO_4$	540	9	9	8	299
0.1 M $CuSO_4$	−540	38	50	30	400
Air		38	53	30	403

Source: I.R. Kramer, B. Wu *et al.*, "Dislocation Distribution in Transgranular Stress Corrosion Cracking of Naval Brass," *Material Science and Engineering*, Vol 82, Sept 1986, 144.

Cuprous Cyanide

Cuprous cyanide, $Cu_2(CN)_2$, white monoclinic crystals, insoluble in H_2O, soluble in HCl, NH_4OH, and potassium cyanide. Used in Sandmeyer's reaction to synthesize aryl cyanides.

Corrosion Behavior of Various Metals and Alloys in Cuprous Cyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Questionable	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Poor	...	253
405	S40500	...	...	Saturated	Boiling	...	Poor	...	253
409	S40900	...	...	Saturated	Boiling	...	Poor	...	253
410	S41000	...	...	Saturated	Boiling	...	Poor	...	253
416	S41600	...	...	Saturated	Boiling	...	Poor	...	253
420	S42000	...	...	Saturated	Boiling	...	Poor	...	253
430	S43000	...	...	Saturated	Boiling	...	Questionable	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Detergent

A synthetic cleansing agent resembling soap in the ability to emulsify oil and hold dirt, and containing surfactants which do not precipitate in hard water; may also contain protein enzymes and whitening agents.

Corrosion Behavior of Various Metals and Alloys in Detergent

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
302	S30200	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
303	S30300	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
303	S30300	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
304	S30400	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
304L	S30403	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
304LN	S30453	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
316	S31600	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
316F	S31620	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
316L	S31603	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
316LN	S31653	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
316Ti	S31635	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
317L	S31703	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
317LN	S31725	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
321	S32100	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
329	S32900	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
347	S34700	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
403	S40300	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
405	S40500	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
409	S40900	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
410	S41000	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
416	S41600	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
420	S42000	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
430	S43000	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
434	S43400	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253
F51	S31803	...	Phosphate detergent	...	95 (203)	...	Resistant	...	253

Dichloroacetic Acid

Dichloroacetic acid, $CHCl_2COOH$, also known as dichlorethanoic acid, is a colorless, strong liquid acid with a boiling point of 194 °C (381 °F). It is soluble in water and alcohol. Dichloroacetic acid is prepared by the chlorination of acetic acid. It is used in organic synthesis.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 in limited laboratory tests at 204 °C (400 °F) was attacked by dichloroacetic acid.

Corrosion Behavior of Various Metals and Alloys in Dichloroacetic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Titanium	...	...	...	100	Boiling	...	0.007 (0.28)	...	90
Zr702	R60702	...	...	100	Boiling	...	0.5 (20) max	...	15

1,1-Dichloroethane

Also ethylidene chloride, CH_3CHCl_2 is a colorless, neutral, mobile liquid with an aromatic ethereal odor and saccharin taste. Soluble in alcohol, ether, fixed and volatile oils and very sparingly soluble in water. It is used as an extraction solvent and fumigant.

Corrosion Behavior of Various Metals and Alloys in 1,1-Dichloroethane

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Dichloroethylene

Also known as acetylene dichloride, ClCHCHCl, is a flammable, toxic, colorless liquid that is slight soluble in water and soluble in alcohol, and which decomposes slowly on exposure to air, light and moisture. It is used in perfumes and lacquers, and also as a general solvent for organic materials

Corrosion Behavior of Various Metals and Alloys in Dichloroethylene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Disulfuryl Chloride

Also pyrosulfuryl chloride, $S_2O_5Cl_2$ is a colorless, mobile, very refractive fuming liquid that decomposes violently with water to sulfuric acid and hydrochloric acid, and is corrosive to tissue. It is used in organic synthesis.

Corrosion Behavior of Various Metals and Alloys in Disulfuryl Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	20 (68)	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Disulfuryl Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	Anhydrous	20 (68)	...	Good	...	253
303	S30300	...	...	Anhydrous	20 (68)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Questionable	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	20 (68)	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	20 (68)	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	20 (68)	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	20 (68)	...	Good	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Questionable	...	253
405	S40500	...	...	Anhydrous	20 (68)	...	Good	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Questionable	...	253
409	S40900	...	...	Anhydrous	20 (68)	...	Good	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Questionable	...	253
410	S41000	...	...	Anhydrous	20 (68)	...	Good	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Questionable	...	253
416	S41600	...	...	Anhydrous	20 (68)	...	Good	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Questionable	...	253
420	S42000	...	...	Anhydrous	20 (68)	...	Good	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Questionable	...	253
430	S43000	...	...	Anhydrous	20 (68)	...	Good	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Questionable	...	253
434	S43400	...	...	Anhydrous	20 (68)	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Questionable	...	253
F51	S31803	...	...	Anhydrous	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Ether

Ether, $(C_2H_5)_2$, also known as ethyl ether, is a colorless liquid with a boiling point of 34.5 °C (93 °F). It is used as a solvent, a denaturant, and as an anesthetic in medicine. It is an organic compound in which two hydrocarbon radicals are joined by an atom of oxygen.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 has excellent resistance to ether at ambient and elevated temperatures in laboratory tests. Ether has been processed, degreased, and handled in aluminum equipment. Valves of 356.0 aluminum alloy have been used successfully to service ether.

Corrosion Behavior of Various Metals and Alloys in Ether

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Crude dichloro ethyl ether	...	80 (175)	71 h	3.050 (120) max	...	39
Electrolytic copper	C11000	...	Dichloro ethyl ether residues	...	80 (175)	94 h	0.915 (36) max	...	39
Electrolytic copper	C11000	...	Dichloro ethyl ether	...	80 (175)	70 h	0.15 (6)	...	39
Electrolytic copper	C11000	...	Dichloro ethyl ether	...	100 (212)	70 h	0.61 (24)	...	39
Electrolytic copper	C11000	...	Dichloro ethyl ether	...	Boiling	70 h	0.183 (7.2)	...	39
Electrolytic copper	C11000	...	Methlybenzyl ether, air atmosphere	...	...	2784 h	0.0025 (0.1) max	...	39
Electrolytic copper	C11000	...	Methylbenzyl ether, N_2 atmosphere	...	...	2784 h	0.0025 (0.1) max	...	39
Electrolytic copper	C11000	...	Recovered butyl ether	...	...	288 h	Resistant	...	39
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Crude dichloro ethyl ether	...	80 (175)	71 h	3.05 (120) max	...	39
Silicon bronze, high	C65500	...	Dichloro ethyl ether	...	80 (175)	70 h	0.12 (4.8)	...	39
Silicon bronze, high	C65500	...	Dichloro ethyl ether	...	100 (212)	70 h	0.245 (9.6)	...	39
Silicon bronze, high	C65500	...	Dichloro ethyl ether	...	Boiling	70 h	0.213 (8.4)	...	39
Silicon bronze, high	C65500	...	Dichloro ethyl ether residues	...	80 (175)	94 h	0.245 (9.6) max	...	39
Silicon bronze, high	C65500	...	Recovered butyl ether	...	...	288 h	0.0025 (0.1)	...	39
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ether (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	7
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Stainless steels									
410	S41000	...	...	...	Room	...	Resistant	...	121

Ethyl Alcohol

Ethyl alcohol, CH_3CH_2OH, also known as ethanol and grain alcohol, is a colorless, volatile liquid with a boiling point of 78.5 °C (172 °F) and a mild characteristic odor. It is soluble in water, chloroform, methyl alcohol, and ether. Ethyl alcohol is a very important commercial and industrial solvent and is used in the manufacture of many food extracts, pharmaceuticals, cleaning products, toiletries, antifreeze compounds, and fuels. Ethyl alcohol burns with a transparent blue flame, producing carbon dioxide and water. The vapor forms an explosive mixture with air and is used under compression as a fuel (gasohol) in some internal combustion engines. The alcoholic beverage industry bases a wide variety of products on the content of ethyl alcohol.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory tests have found that anhydrous ethyl alcohol corrodes aluminum alloys. However, in other laboratory tests, aluminum alloy 3003 resisted corrosion from aqueous solutions of ethyl alcohol up to 95% (commercial grade). Industry uses aluminum alloy equipment such as stills, heat exchangers, tanks, and piping for processing ethyl alcohol and products manufactured using ethyl alcohol.

Corrosion Behavior of Various Metals and Alloys in Ethyl Alcohol

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	10
Nickel and alloys									
Alloy 825	N08825	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1)	...	89
Refractory metals and alloys									
Titanium	...	...	...	95	Boiling	...	0.013 (0.5)	...	20
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	...	21 (70)	...	Good	...	121
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.1% butyric acid, 0.5% sulfuric acid, 1% acetic acid, 5% ethyl acetate, 15% water	56	75 (167)	59 d	0.03 (1)	...	89
304	S30400	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Sensitized specimens. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.5 (20)	...	89
304	S30400	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. With carbon over the standard maximum. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1)	...	89
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	...	21 (70)	...	Resistant	...	121
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.1% butyric acid, 0.5% sulfuric acid, 1% acetic acid, 5% ethyl acetate, 15% water	56	75 (167)	59 d	0.01 (0.4)	...	89
316	S31600	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1) max	...	89
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317	S31700	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1) max	...	89
317	S31700	Sensitized	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1) max	...	89
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	Boiling	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	Boiling	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	Boiling	...	Resistant	...	253
410	S41000	...	...	...	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	All concentrations	Boiling	...	Resistant	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	Boiling	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	Boiling	...	Resistant	...	253
430	S43000	...	...	...	21 (70)	...	Good	...	121
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
Carpenter 20	...	...	Plastic processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.5% sulfuric acid, 1% butyraldehyde, 5% ethyl acetate, 15% water, 23% solids	56	75 (167)	132 d	0.003 (0.1) max	...	89
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Ethyl Chloride

Ethyl chloride, CH_3CH_2Cl, also known as chlorethane, hydrochloric ether, and muriatic ether, is a colorless liquid or gas. It has a boiling point of 12.2 °C (54 °F), is soluble in alcohol and ether, and is slightly soluble in water. Ethyl chloride is used as a solvent for oils, resins, and waxes. It is used in medicine and as an intermediate in synthesis.

Corrosion Behavior of Various Metals and Alloys in Ethyl Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	Wet and acid products	...	Boiling	...	0.05 (2) max	...	7
Platinum	P04995	...	Wet and acid products	...	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	Wet and acid products	...	Boiling	...	0.05 (2) max	...	10
Refractory metals and alloys									
Titanium	...	...	...	100	Boiling	...	0.13 (5) max	...	20
Zr702	R60702	...	...	100	Boiling	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	Anhydrous	0 (32)	...	Resistant	...	253
302	S30200	...	...	Anhydrous	0 (32)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	0 (32)	...	Resistant	...	253
303	S30300	...	...	Anhydrous	0 (32)	...	Resistant	...	253
304	S30400	...	...	Anhydrous	0 (32)	...	Resistant	...	253
304	S30400	...	Chemical processing; lab test; no aeration. 1,2-dichloroethane	...	501-557 (935-1035)	1 d	0.75 (30)	...	89
304L	S30403	...	...	Anhydrous	0 (32)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethyl Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	Anhydrous	0 (32)	...	Resistant	...	253
316	S31600	...	...	Anhydrous	0 (32)	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	0 (32)	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	0 (32)	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	0 (32)	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	0 (32)	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	0 (32)	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	0 (32)	...	Resistant	...	253
321	S32100	...	...	Anhydrous	0 (32)	...	Resistant	...	253
329	S32900	...	...	Anhydrous	0 (32)	...	Resistant	...	253
347	S34700	...	...	Anhydrous	0 (32)	...	Resistant	...	253
403	S40300	...	...	Anhydrous	0 (32)	...	Resistant	...	253
405	S40500	...	...	Anhydrous	0 (32)	...	Resistant	...	253
409	S40900	...	...	Anhydrous	0 (32)	...	Resistant	...	253
410	S41000	...	...	Anhydrous	0 (32)	...	Resistant	...	253
416	S41600	...	...	Anhydrous	0 (32)	...	Resistant	...	253
420	S42000	...	...	Anhydrous	0 (32)	...	Resistant	...	253
430	S43000	...	...	Anhydrous	0 (32)	...	Resistant	...	253
434	S43400	...	...	Anhydrous	0 (32)	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	0 (32)	...	Resistant	...	253

Ethyl Ether

Also known as diethyl ether, or sulfuric ether, $(C_2H_5)_2O$ is a very flammable, colorless, mobile liquid, which is slightly soluble in water and soluble in alcohol. Used as an anesthetic and industrial solvent, and in organic synthesis, ethyl ether melts at –16.3 °C and boils at 34.6 °C.

Corrosion Behavior of Various Metals and Alloys in Ethyl Ether

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethyl Ether (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Ethylene Glycol

Ethylene glycol, CH_2OHCH_2OH, also known as glycol, ethylene alcohol, glycol alcohol, and dihydric alcohol, is a colorless liquid with a boiling point of 197.2 °C (385 °F). It is soluble in water and in alcohol. Ethylene glycol has a low freezing point, –25 °C (–13 °F), and is widely used as an antifreeze in automobiles and in hydraulic fluids. It is used as a solvent for nitrocellulose and in the manufacture of acrylonitrile, dynamites, and resins.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 resists ethylene glycol under laboratory test conditions of both ambient temperature and refluxing, boiling, and condensing temperatures. Ethylene glycol has been processed and stored in aluminum alloy equipment. Automobile aluminum radiators and heat exchangers use inhibited ethylene glycol/water solutions for antifreeze protection. Violent reactions in aluminum alloys are possible if stagnant ethylene glycol is present at 200 °C (392 °F) or above.

Corrosion Behavior of Various Metals and Alloys in Ethylene Glycol

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
10% Al bronze	C61800	...	Ethylene glycol solution. Plus 0.03-0.05% H_2SO_4. Second run	15	99 (210)	2400 h	0.48 (19)	...	122
5% Al bronze	C60800	...	Ethylene glycol solution. Plus 0.03% H_2SO_4	15	99 (210)	2880 h	0.0075 (0.3) max	...	122
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Ethylene glycol solution. Plus 0.03-0.05% H_2SO_4. Second run	15	99 (210)	2400 h	0.46 (18)	...	122
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	Triethylene glycol air conditioning system	...	175 (345)	2560 h	0.05 (2.0)	...	122

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethylene Glycol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cartridge brass	C26000	...	Triethylene glycol air conditioning system	...	175 (345)	3320 h	0.015 (0.6)	...	122
Cartridge brass	C26000	...	Triethylene glycol air conditioning system	...	175 (345)	8328 h	0.034 (1.4)	...	122
Cartridge brass	C26000	...	Triethylene glycol air conditioning system	...	160 (320)	2880 h	0.0075 (0.3)	...	122
Cartridge brass	C26000	...	Triethylene glycol air conditioning system	...	160 (320)	5760 h	0.0025 (0.1)	...	122
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Copper	...	...	pH 7, 5 ppm PTH, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.005 (0.2)	...	197
Copper	...	...	pH 7, 5 ppm PTH, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.01 (0.4)	...	197
Copper	...	...	pH 7, 50 ppm DMP, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.01 (0.5)	...	197
Copper	...	...	pH 7, 50 ppm DMP, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.03 (1.2)	...	197
Copper	...	...	pH 7, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.08 (3.1)	...	197
Copper	...	...	pH 7, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.15 (5.9)	...	197
Copper	...	...	pH 8.5, 5 ppm PTH, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.003 (0.1) max	...	197
Copper	...	...	pH 8.5, 5 ppm PTH, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.003 (0.1)	...	197
Copper	...	...	pH 8.5, 50 ppm DMP, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.01 (0.3)	...	197
Copper	...	...	pH 8.5, 50 ppm DMP, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.01 (0.4)	...	197
Copper	...	...	pH 8.5, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	70	1200 h	.04 (1.5)	...	197
Copper	...	...	pH 8.5, contains 100 ppm SO_4^{2-}, 100 ppm Cl^-, 100 ppm HCO_3^-	30	60	1200 h	.03 (1.0)	...	197
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Ethylene glycol solution. Plus 0.03-0.05% H_2SO_4. Second run	15	99 (210)	2400 h	0.58 (23)	...	122
Electrolytic copper	C11000	...	Glycol maleate	...	79 (175)	3050 h	0.02 (0.8)	...	122
Electrolytic copper	C11000	...	Triethylene glycol air conditioning system	...	175 (345)	2560 h	0.04 (1.6)	...	122
Electrolytic copper	C11000	...	Triethylene glycol air conditioning system	...	175 (345)	3320 h	0.01 (0.4)	...	122
Electrolytic copper	C11000	...	Triethylene glycol air conditioning system	...	175 (345)	8328 h	0.025 (1.0)	...	122
Electrolytic copper	C11000	...	Triethylene glycol air conditioning system	87-95	160 (320)	2880 h	0.0075 (0.3)	...	122
Electrolytic copper	C11000	...	Triethylene glycol air conditioning system	...	160 (320)	5760 h	0.0025 (0.1)	...	122
Electrolytic copper	C11000	...	Triethylene glycol solution, aerated	...	Room	1344 h	Resistant	...	122

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethylene Glycol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Ni-Al bronze	C63000	...	Ethylene glycol solution. Plus 0.03% H_2SO_4	15	99 (210)	2880 h	0.18 (0.7) max	...	122
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Ethylene glycol solution. Plus 0.03% H_2SO_4	15	99 (210)	2880 h	0.01 (0.4) max	...	122
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Ethylene glycol solution. Plus 0.03% H_2SO_4	15	99 (210)	2880 h	0.025 (1.0) max	...	122
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	May need inhibitors	...	Room	...	Resistant	...	119
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Good	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	All	21 (70)	...	Resistant	...	121
304	S30400	...	Pharmaceutical processing; field or pilot plant test; no aeration; no agitation	...	-34 (-30)	112 d	0.003 (0.1)	...	89
304	S30400	...	Pharmaceutical processing; field or pilot plant test; no aeration; no agitation	...	46 (115)	112 d	0.003 (0.1)	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	All	21 (70)	...	Resistant	...	121
316	S31600	...	Pharmaceutical processing; field or pilot plant test; no aeration; no agitation	...	-34 (-30)	112 d	0.003 (0.1)	...	89
316	S31600	...	Pharmaceutical processing; field or pilot plant test; no aeration; no agitation	...	46 (115)	112 d	0.003 (0.1)	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Questionable	...	253
405	S40500	...	...	...	20 (68)	...	Questionable	...	253
409	S40900	...	...	...	20 (68)	...	Questionable	...	253
410	S41000	...	...	...	20 (68)	...	Questionable	...	253
410	S41000	...	...	All	21 (70)	...	Resistant	...	121
416	S41600	...	...	...	20 (68)	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethylene Glycol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	...	20 (68)	...	Questionable	...	253
430	S43000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	All	21 (70)	...	Resistant	...	121
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Fatty Acids

Fatty acids, $C_nH_{2n+1}COOH$, are organic acids of the aliphatic or open-chain structure. They are found in the form of glycerol esters in common animal fats and vegetable fatty oils, hence the name "fatty acids." They are very stable and only weakly acidic, their acidic qualities decreasing with increasing formula weight. The simplest member of the group is formic acid. Other examples are butyric acid, valeric acid, palmitic acid, stearic acid, and oleic acid. These acids react with alcohol to form esters and water. Fatty acids are used as lubricants in cosmetics and in soaps and detergents.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Iron. Unalloyed cast iron can be used to handle concentrated fatty acids, but will be attacked by more dilute solutions. Austenitic nickel cast irons exhibit adequate resistance to stearic acid.

Aluminum. Aluminum alloy 1100 is mildly attacked by fatty acids at ambient temperature in laboratory tests. Anhydrous fatty acids at the boiling point were very corrosive to aluminum alloys in other tests. Fatty acids and their derivatives have been processed and handled in aluminum alloy storage tanks, settling and receiving tanks, separators, condensors, and vapor and steam trace lines.

Copper. Fatty acids attack copper and copper alloys in the presence of moisture and air. The rate of attack is also influenced by the temperature and presence of impurities. Copper alloys C11000, C26000, and C65500 had corrosion rates of 0.50 to 1.25 mm/yr (20 to 50 mils/yr) when tested at 25 to 100 °C (75 to 212 °F) in stearic acid. Under severe conditions, fatty acids attack copper alloys at a higher rate than other organic acids. Specimens of C71000 (copper nickel, 20%) and C71500 (copper nickel, 30%) had corrosion rates of 0.064 mm/yr (2.6 mils/yr) and 0.059 mm/yr (2.4 mils/yr), respectively, when submerged just below the liquid level in tests conducted for 400 h in a copper-lined wooden splitting tank containing a mixture of 60% fatty acids, 30% water, and 1.17% sulfuric acid heated to 100 °C (212 °F) and agitated violently with an open steam jet. Similar specimens of C71000 and C71500, when submerged to 150 mm (6 in.) from the tank bottom, had corrosion rates of 0.178 and 0.185 mm/yr (7.0 and 7.3 mils/yr), respectively.

Nickel. In general, fatty acids such as stearic and lauric acid are not very corrosive to nickel-base alloys. Inorganic impurities such as chlorides and oxidizing salts in the fatty acids determine the corrosion rate.

Corrosion Behavior of Various Metals and Alloys in Fatty Acids

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	...	...	Higher. Commercial	...	20-Boiling (68-Boiling)	...	Questionable	...	92
Aluminum-manganese alloys	...	...	Higher. Commercial	...	20-Boiling (68-Boiling)	...	Questionable	...	92
Carbon and alloys									
Steel	G10100	...	Butyric acid	...	Room	...	0.15 (6)	...	22
Copper and alloys									
70-30 cupronickel	C71500	...	Palmitic acid	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ethylene Glycol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	...	20 (68)	...	Questionable	...	253
430	S43000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	All	21 (70)	...	Resistant	...	121
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Fatty Acids

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	...	...	Higher. Commercial	...	20-Boiling (68-Boiling)	...	Questionable	...	92
Aluminum-manganese alloys	...	...	Higher. Commercial	...	20-Boiling (68-Boiling)	...	Questionable	...	92
Carbon and alloys									
Steel	G10100	...	Butyric acid	...	Room	...	0.15 (6)	...	22
Copper and alloys									
70-30 cupronickel	C71500	...	Palmitic acid	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Fatty Acids (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	Palmitic acid	...	...	...	Good	...	93
Admiralty brass	C44300	...	Palmitic acid	...	...	...	Good	...	93
Aluminum bronze	...	...	Palmitic acid	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (2) max	...	96
Architectural bronze	C38500	...	Palmitic acid	...	...	...	Questionable	...	93
Brass	...	...	Palmitic acid	...	...	...	Good	...	93
Cartridge brass	C26000	...	Palmitic acid	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	Palmitic acid	...	...	...	Good	...	93
Copper	...	...	Butyric acid	...	Room	...	0.05 (2)	...	22
Electrolytic copper	C11000	...	Palmitic acid	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Palmitic acid	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Palmitic acid	...	...	...	Questionable	...	93
Naval brass	C46400	...	Palmitic acid	...	...	...	Questionable	...	93
Nickel-silver	...	...	Palmitic acid	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Palmitic acid	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Palmitic acid	...	...	...	Good	...	93
Phosphor copper	C12200	...	Palmitic acid	...	...	...	Good	...	93
Red brass	C23000	...	Palmitic acid	...	...	...	Good	...	93
Silicon bronze	...	...	Butyric acid	...	Room	...	0.5 (2)	...	22
Silicon bronze, high	C65500	...	Palmitic acid	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Palmitic acid	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	8
Magnesium	...	...	...	All	Room	...	Poor	...	119
Platinum	P04995	...	...	Pure	400 (750)	...	0.05 (2) max	...	6
Silver	P07010	...	...	...	400 (750)	...	0.05 (2) max	...	4
Silver	P07010	...	...	...	400 (750)	...	0.05 (2) max	...	4
Silver	P07010	...	...	Pure	400 (750)	...	0.05 (2) max	...	10
Silver	P07010	...	Butyric acid	...	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	Butyric acid	...	Boiling	...	0.05 (2) max	...	4
Tin	...	...	$>C_6$	...	100 (212)	...	Poor	...	94
Tin	...	...	$>C_6$	...	20 (68)	...	Resistant	...	94
Tin	...	...	$>C_6$	...	60 (140)	...	Resistant	...	94
Refractory metals and alloys									
Titanium	...	...	Butyric acid. Normal, undiluted	...	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	Hot	...	Questionable	...	253
302	S30200	...	...	...	Hot	...	Questionable	...	253
303	S30300	...	...	...	Hot	...	Questionable	...	253
304	S30400	...	...	...	Hot	...	Questionable	...	253
304	S30400	...	...	100	21 (70)	...	Good	...	121
304	S30400	...	Butyric acid	...	115 (240)	...	0.08 (3)	...	22
304	S30400	...	Butyric acid	...	Boiling	...	1.42 (56)	...	22
304	S30400	...	Butyric acid	...	Room	...	0.02 (1) max	...	22
304	S30400	...	Soap (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Animal fatty acids, 60% free pitch (high-vacuum column)	40	226 (440)	163 d	0.003 (0.1) max	...	89
304	S30400	...	Soap (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Fatty acids vapor and liquid from animal foot, 20% stripping steam (high-vacuum column)	90	215 (420)	163 d	0.01 (0.5)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Fatty Acids (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Soap (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Fatty acids vapor and liquid from animal foot, 20% stripping steam (high-vacuum column)	90	215 (420)	163 d	0.005 (0.2)	...	89
304	S30400	Crevice attack	Chemical (distillation) processing; field or pilot plant test; strong aeration; slight to moderate agitation. Crude fatty acids, mixed	...	100 (212)	43 d	0.53 (21)	...	89
304L	S30403	...	...	...	Hot	...	Questionable	...	253
304LN	S30453	...	...	...	Hot	...	Questionable	...	253
316	S31600	...	...	...	Hot	...	Good	...	253
316	S31600	...	...	100	21 (70)	...	Resistant	...	121
316	S31600	...	Butyric acid	...	115 (240)	...	0.076 (3)	...	22
316	S31600	...	Butyric acid	...	Boiling	...	0.127 (5)	...	22
316	S31600	...	Butyric acid	...	Room	...	0.0254 (1) max	...	22
316	S31600	...	Soap (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Animal fatty acids, 60% free pitch (high-vacuum column)	40	226 (440)	163 d	0.003 (0.1) max	...	89
316	S31600	...	Soap (distillation) processing; field or pilot plant test; no aeration; rapid agitation. Fatty acids vapor and liquid from animal foot, 20% stripping steam (high-vacuum column)	90	215 (420)	163 d	0.003 (0.1) max	...	89
316	S31600	Crevice attack	Chemical (distillation) processing; field or pilot plant test; strong aeration; slight to moderate agitation. Crude fatty acids, mixed	...	100 (212)	43 d	0.12 (4.9)	...	89
316F	S31620	...	...	...	Hot	...	Questionable	...	253
316L	S31603	...	...	...	Hot	...	Good	...	253
316LN	S31653	...	...	...	Hot	...	Good	...	253
316Ti	S31635	...	...	...	Hot	...	Good	...	253
317L	S31703	...	...	...	Hot	...	Good	...	253
317LN	S31725	...	...	...	Hot	...	Good	...	253
321	S32100	...	...	...	Hot	...	Questionable	...	253
329	S32900	...	...	...	Hot	...	Good	...	253
347	S34700	...	...	...	Hot	...	Questionable	...	253
410	S41000	...	...	100	21 (70)	...	Good	...	121
430	S43000	...	...	100	21 (70)	...	Good	...	121
434	S43400	...	...	...	Hot	...	Poor	...	253
F51	S31803	...	...	...	Hot	...	Good	...	253

Ferric Chloride

Ferric chloride, $FeCl_3$, is a brown crystalline solid that melts at 300 °C and is soluble in water, alcohol, and glycerol. It is also known as anhydrous ferric chloride, ferric trichloride, Flores martis, and iron chloride. Ferric chloride is used as a coagulant for sewage and industrial wastes, as an oxidizing and chlorinating agent, as a disinfectant, in copper etching, and as a mordant. In addition, this compound is employed in the ferric chloride test, which is used to assess the relative corrosion resistance of stainless and nickel-base alloys. The ferric chloride test has been shown to be an appropriate measure of the suitability of such alloys for service in paper mill bleach plants and seawater.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Aluminum bronzes should be avoided for service in ferric chloride.

Metallic Glasses. The tendency of glassy $Fe_{40}Ni_{40}P_{14}B_6$ to undergo stress-corrosion cracking and hydrogen embrittlement in acidic electrolytes was studied. Specimens immersed in aqueous ferric chloride solution at the free corrosion potential failed by stress-corrosion cracking.

The corrosion behavior of glassy alloys is strongly influenced by additions of metallic elements, especially those that form films on the alloy surface, that is, film former additions. The beneficial effect of chromium additions has been demonstrated for glassy iron-base, cobalt-base, and nickel-base alloys. In one study, it was shown that a chromium content of 7 at.% in a glassy Ni-Cr-$P_{15}B_5$ alloy resulted in an undetectably small corrosion rate in 10% ferric chloride.

Osmium. Osmium is dissolved fairly rapidly in ferric chloride at 100 °C (212 °F).

Platinum. A 10% addition of rhodium to platinum reduces the corrosion rate in 100 g/L ferric chloride at 100 °C (212 °F) from 16.7 to 0.2 mm/yr (660 to 50 mils/yr). Alloys containing more than 60% Ag are rapidly attacked by ferric chloride.

Palladium. Palladium is generally resistant to corrosion by most single acids, alkalis, and aqueous solutions of many common salts, but when air is present it is attacked by ferric chloride. In a 100 g/L solution of ferric chloride, a 10% addition of platinum decreased the room-temperature corrosion rate of palladium from 11.9 to 8.6 mm/yr (469 to 339 mils/yr). A 30% platinum addition further decreased the corrosion rate to 1.8 mm/yr (71 mils/yr).

Titanium. Halid salts of oxidizing cationic species enhance the passivity of titanium alloys such that negligible corrosion rates can be expected. Examples include ferric chloride, cupric chloride, and nickel chloride solutions and their bromide counterparts.

Zirconium. Zirconium is highly resistant to corrosion by most saline solutions, but ferric chloride is an exception. Ferric chloride attacks zirconium, causing stress-corrosion cracking.

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Iridium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Lead	L50045	...	...	100 g/L	100 (212)	...	Poor	...	17
Lead	L50045	...	...	100 g/L	Room	...	11.9 (469)	...	17
Lead	L50045	...	...	20-30	24 (75)	...	1.3 (50) min	...	95
Magnesium	...	...	...	All	Room	...	Poor	...	119
Osmium	...	...	...	100 g/L	100 (212)	...	3.0 (120)	...	26

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Platinum	P04995	...	...	100 g/L	100 (212)	...	16.7 (6.57)	...	5
Platinum	P04995	...	...	100 g/L	Room	...	0.25 (10) max	...	5
Rhodium	P05990	...	...	100 g/L	100 (212)	...	Resistant	...	29
Ruthenium	...	...	...	100 g/L	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	5 max	Room	...	0.05 (2)	...	9
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Nickel and alloys									
Alloy 825	...	...	Field or pilot plant test; slight to moderate aeration; no agitation	~36	25 (77)	61 d	Poor	...	89
Alloy 825	N08825	...	Chemical processing; slight aeration; rapid agitation. Containing ammonia and fatty acids	...	102 (216)	106 d	0.003 (0.1) max	...	89
Inco C-276	N10276	...	...	10	50 (122)	100 h	0.005 (0.2)	Crevice corrosion	40
Inco C-276	N10276	...	...	10	75 (167)	100 h	0.036 (1.4)	Crevice corrosion	40
Incoloy 800	N08800	Cold-rolled, annealed sheet., 2.84 mm (0.112 in.) thick	Solutions were prepared with reagent-grade chemicals	5	80 (176)	42 d	10.7 (420)	Pitting occured after 7d	44
Inconel 601	N06601	...	...	5	80 (176)	7 d	8.99 (354)	Pitting attack. Average of two tests	64
Refractory metals and alloys									
44Co-31Cr-13W	...	As cast	Based on five 24-h test periods	2	Room	...	0.07 (3)	...	53
44Co-31Cr-13W	...	As cast	Based on five 24-h test periods	2	Room	...	0.07 (3)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	Based on five 24-h test periods	2	Room	...	0.25 (10)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	Based on five 24-h test periods	89	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	Based on five 24-h test periods	2	Room	...	0.25 (10)	...	53
50Co-20Cr-15W-10Ni	...	...	...	2	Room	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	As cast	Based on five 24-h test periods	2	Room	...	Resistant	...	53
53Co-30Cr-4.5W	...	As cast	Based on five 24-h test periods	2	Room	...	0.005 (0.2)	...	53
53Co-30Cr-4.5W	...	As cast	Based on five 24-h test periods	2	Room	...	0.005 (0.2)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	Based on five 24-h test periods	2	Room	...	0.005 (0.2)	...	53
53Co-30Cr-4.5W	...	Heat treated 4h at 899°C (1650°F)	Based on five 24-h test periods	2	Room	...	0.005 (0.2)	...	53
Co-Cr-Ni	R31233	...	...	10	Boiling	...	119 (4760)	...	196
Co-Cr-Ni	R31233	...	...	10	Boiling	...	54 (2160)	...	196
Co-Cr-Ni	R31233	...	...	10	Boiling	...	6.2 (248)	...	196
Co-Cr-Ni	R31233	...	...	10	Boiling	...	69 (2760)	...	196
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	10	Boiling	...	18 (7)	...	196
Haynes No. 188	R30188	Mill annealed	...	3.8	70 (160)	24 h	Resistant	...	99
Haynes No. 188	R30188	Mill annealed	...	3.8	Boiling	24 h	Resistant	...	99
Haynes No. 188	R30188	Mill annealed	...	3.8	Room	24 h	Resistant	...	99

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods	2	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	All data are steady-state as calculated from a minimum of five 24-h test periods	10	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Plus 5% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	2	Boiling	24 h	Resistant	...	68
Haynes No. 25	R30605	12-gage, solution heat-treated sheet	Plus 10% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	5	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	12-gage, solution heat-treated sheet	Plus 5% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	2	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	Mill annealed	...	3.8	70 (160)	24 h	Resistant	...	99
Haynes No. 25	R30605	Mill annealed	...	3.8	Boiling	24 h	Resistant	...	99
Haynes No. 25	R30605	Mill annealed	...	3.8	Room	24 h	0.013 (0.5)	...	99
Haynes No. 556	R30556	Mill annealed	...	3.8	70 (160)	24 h	14 (550)	...	99
Haynes No. 556	R30556	Mill annealed	...	3.8	Boiling	24 h	36 (1419)	...	99
Haynes No. 556	R30556	Mill annealed	...	3.8	Room	24 h	0.033 (1.3)	...	99
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods	2	Room	24 h	Resistant	...	68
Multimet	R30155	...	All data are steady-state as calculated from a minimum of five 24-h test periods	10	Room	24 h	Resistant	...	68
Multimet	R30155	12-gage, solution heat-treated sheet	Plus 10% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	5	66 (150)	24 h	25.4 (1000) max	...	68
Multimet	R30155	12-gage, solution heat-treated sheet	Plus 5% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	2	66 (150)	24 h	4.90 (193)	...	68
Multimet	R30155	12-gage, solution heat-treated sheet	Plus 5% NaCl. All data are steady-state as calculated from a minimum of five 24-h test periods	2	Boiling	24 h	25.4 (1000) max	...	68
Niobium	R04210	...	...	10	19-26 (65-80)	36 d	Resistant	...	74
Niobium	R04210	...	...	10	Boiling	...	Resistant	...	2
Niobium	R04210	...	...	10	Room	...	Resistant	...	2
Niobium	R04210	Wrought 0.75% Zr, bal Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Wrought 100% Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Wrought 100% Cb; electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium	R04210	Wrought 100% Cb; lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Wrought 6.9% Ti, 0.81% Zr, bal Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Wrought 8% Ti, bal Cb; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	30	Boiling	48 h	0.025 (1) max	...	38
Tantalum	R05210	...	...	10	19-26 (65-80)	36 d	Resistant	...	74
Tantalum	R05210	Commercial sheet	...	30	Boiling	48 h	0.025 (1) max	...	38
Tantalum	R05210	High purity	...	30	Boiling	48 h	0.025 (1) max	...	38
Ti-10-2-3	...	...	...	10	Boiling	...	Resistant	...	33
Ti-3-8-6-4-4	R58640	...	...	10	Boiling	...	Resistant	...	33
Ti-550	...	...	...	10	Boiling	...	Resistant	...	33
Ti-5Ta	...	...	...	10	Boiling	...	Resistant	...	33
Ti-6-2-1	...	...	...	10	Boiling	...	Resistant	...	33
Ti-6-2-4-6	R56260	...	...	10	Boiling	...	0.06 (2.4)	...	33
Ti-6-4	R56400	...	...	10	Boiling	...	Resistant	...	33
Titanium	...	...	...	1-30	100 (212)	...	0.004 (0.16)	...	90
Titanium	...	...	...	1-30	Boiling	...	Resistant	...	90
Titanium	...	...	...	10	19-26 (65-80)	36 d	0.00076 (0.03)	...	74
Titanium	...	...	...	10	Boiling	...	0.00 (0.00)	...	90
Titanium	...	...	...	10-20	Room	...	Resistant	...	90
Titanium	...	...	...	10-40	Boiling	...	Resistant	...	90
Titanium	...	...	...	50	150 (302)	...	0.003 (0.12)	...	90
Titanium, grade 12	R53400	...	...	10	Boiling	...	Resistant	...	33
Titanium, grade 12	R53400	...	Tight crevice, pH 0.6	10	Boiling	...	Poor	...	215
Titanium, grade 16	...	...	Tight crevice, pH 0.6	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevice, pH 0.6	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevice, pH 0.6	10	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	...	10	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	...	30	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	Tight crevice, pH 0.6	10	Boiling	...	Resistant	...	215
Titanium, grade 9	...	...	...	10	Boiling	...	Resistant	...	33
Transage 207	...	...	...	10	Boiling	...	0.19 (7.6)	...	33
Zircaloy 2	R60802	As received	...	10	...	100 h	2.5 (112)	...	230
Zircaloy 2	R60802	Grit blasted	...	10	RT	100 h	8.3 (328)	...	230
Zircaloy 2	R60802	Laser alloyed with Cr	...	10	...	100 h	.74 (29)	...	230
Zircaloy 2	R60802	Laser alloyed with Ni	...	10	...	100 h	.43 (17)	...	230
Zircaloy 2	R60802	Laser glazed	...	10	...	100 h	.28 (11)	...	230
Zirconium	R60701	...	Uneven corrosion	10	19-26 (65-80)	36 d	0.01 (0.42)	...	74
Zr702	R60702	...	...	0-50	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	...	0-50	Room to 100 (Room to 212)	...	1.3 (50) min	...	15
Zr704	R60704	...	...	0-50	Boiling	...	1.3 (50) min	...	15
Zr704	R60704	...	...	0-50	Room to 100 (Room to 212)	...	1.3 (50) min	...	15
Zr705	R60705	...	...	0-50	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	...	0-50	Room to 100 (Room to 212)	...	1.3 (50) min	...	15

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
18Cr-1V	...	...	...	6	23	72 h	8.2 (330)	...	234
18Cr-1V-0.7Ti	...	...	...	6	23	72 h	8.5 (341)	...	234
18Cr-1V-1Ni	...	...	...	6	23	72 h	9.2 (367)	...	234
18Cr-2.6V	...	...	...	6	23	72 h	12.2 (487)	...	234
18Cr-2.6V-0.7Ti	...	...	...	6	23	72 h	3.1 (125)	...	234
18Cr-2.6V-1Ni-.10Ti	...	...	...	6	23	72 h	10.0 (399)	...	234
18Cr-2Ni-12Mn	S24100	...	...	10 wt%	Room	...	0.025 (1) max	...	47
18Cr-4V	...	...	...	6	23	72 h	9.1 (363)	...	234
18Cr-4V-.09Nb	...	...	...	6	23	72 h	2.9 (116)	...	234
18Cr-4V-.11Ti	...	...	...	6	23	72 h	0.6 (25.3)	...	234
18Cr-4V-0.9Mo-.11Ti	...	...	...	6	23	72 h	0.01 (0.4)	...	234
18Cr-4V-1.5Ni-.11Ti	...	...	...	6	23	72 h	1.8 (72.9)	...	234
18Cr-4V-1.5Ni-1.1Cu	...	...	...	6	23	72 h	6.5 (258)	...	234
18Cr-4V-1.5Ni-1.5Si	...	...	...	6	23	72 h	0.2 (8.0)	...	234
18Cr-4V-1Ni-.12Ti	...	...	...	6	23	72 h	0.3 (12.2)	...	234
18Cr-4V-2Ni-.12Ti	...	...	...	6	23	72 h	1.5 (59.1)	...	234
301	S30100	...	...	30	20 (68)	...	Poor	Pitting	253
301	S30100	...	...	50	50 (122)	...	Poor	Pitting	253
302	S30200	...	...	30	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	50	50 (122)	...	Poor	Pitting	253
303	S30300	...	...	30	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	30	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	50	50 (122)	...	Poor	Pitting	253
303	S30300	...	...	50	50 (122)	...	Poor	Pitting	253
304	S30400	...	...	10	21 (70)	...	Poor	...	121
304	S30400	...	...	30	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	50	50 (122)	...	Poor	Pitting	253
304	S30400	...	Research lab test	10	Room	1 d	4 (150)	...	89
304L	S30403	...	...	30	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	50	50 (122)	...	Poor	Pitting	253
304LN	S30453	...	...	30	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	50	50 (122)	...	Poor	Pitting	253
316	S31600	...	...	10	21 (70)	...	Poor	...	121
316	S31600	...	...	10	Room	...	16 (640)	...	51
316	S31600	...	...	30	20 (68)	...	Questionable	Pitting	253
316	S31600	...	...	50	50 (122)	...	Poor	Pitting	253
316	S31600	...	Chemical processing; slight aeration; rapid agitation. Containing ammonia and fatty acids	...	102 (216)	106 d	0.003 (0.1) max	...	89
316	S31600	...	Field or pilot plant test; slight to moderate aeration; no agitation	~36	25 (77)	61 d	Poor	...	89
316F	S31620	...	...	30	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	50	50 (122)	...	Poor	Pitting	253
316L	S31603	...	...	30	20 (68)	...	Questionable	Pitting	253
316L	S31603	...	...	50	50 (122)	...	Poor	Pitting	253
316LN	S31653	...	...	30	20 (68)	...	Questionable	Pitting	253
316LN	S31653	...	...	50	50 (122)	...	Poor	Pitting	253
316Ti	S31635	...	...	30	20 (68)	...	Questionable	Pitting	253
316Ti	S31635	...	...	50	50 (122)	...	Poor	Pitting	253
317L	S31703	...	...	30	20 (68)	...	Questionable	Pitting	253
317L	S31703	...	...	50	50 (122)	...	Poor	Pitting	253
317LN	S31725	...	...	30	20 (68)	...	Questionable	Pitting	253
317LN	S31725	...	...	50	50 (122)	...	Poor	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	30	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	50	50 (122)	...	Poor	Pitting	253
329	S32900	...	...	30	20 (68)	...	Questionable	Pitting	253
329	S32900	...	...	50	50 (122)	...	Poor	Pitting	253
347	S34700	...	...	30	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	50	50 (122)	...	Poor	Pitting	253
3CR12	...	...	12Cr-0 Mo	0.6	35	4 d	...	Maximum pitting 0.49 (20)	239
3CR12	...	...	12Cr-0.1 Mo	0.6	35	4 d	...	Maximum pitting 0.53 (21)	239
3CR12	...	...	12Cr-0.2 Mo	0.6	35	4 d	...	Maximum pitting 0.24 (10)	239
3CR12	...	...	12Cr-0.3 Mo	0.6	35	4 d	...	Maximum pitting 0.81 (32)	239
3CR12	...	...	12Cr-0.5 Mo	0.6	35	4 d	...	Maximum pitting 0.61 (24)	239
3CR12	...	...	12Cr-0.9 Mo	0.6	35	4 d	...	Maximum pitting 0.79 (32)	239
3CR12	...	...	12Cr-1.8 Mo	0.6	35	4 d	...	Maximum pitting 0.90 (36)	239
3CR12	...	Stabilized with Ti	12Cr-0 Mo	0.6	35	4 d	...	Maximum pitting 0.26 (10)	239
3CR12	...	Stabilized with Ti	12Cr-0.1 Mo	0.6	35	4 d	...	Maximum pitting 0.06 (42)	239
3CR12	...	Stabilized with Ti	12Cr-0.2 Mo	0.6	35	4 d	...	Maximum pitting 1.56 (62)	239
3CR12	...	Stabilized with Ti	12Cr-0.3 Mo	0.6	35	4 d	...	Maximum pitting 0.75 (30)	239
3CR12	...	Stabilized with Ti	12Cr-0.5 Mo	0.6	35	4 d	...	Maximum pitting 1.33 (53)	239
3CR12	...	Stabilized with Ti	12Cr-1.0 Mo	0.6	35	4 d	...	Maximum pitting 0.50 (20)	239
3CR12	...	Stabilized with Ti	12Cr-2.0 Mo	0.6	35	4 d	...	Maximum pitting 0.84 (34)	239
403	S40300	...	...	30	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	50	50 (122)	...	Poor	Pitting	253
405	S40500	...	...	30	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	50	50 (122)	...	Poor	Pitting	253
409	S40900	...	...	30	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	50	50 (122)	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	10	21 (70)	...	Poor	...	121
410	S41000	...	...	30	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	50	50 (122)	...	Poor	Pitting	253
416	S41600	...	...	30	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	50	50 (122)	...	Poor	Pitting	253
420	S42000	...	...	30	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	50	50 (122)	...	Poor	Pitting	253
430	S43000	...	...	10	21 (70)	...	Poor	...	121
430	S43000	...	...	30	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	50	50 (122)	...	Poor	Pitting	253
430	S43000	...	...	6	23	72 h	21.2 (847)	...	234
434	S43400	...	...	30	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	50	50 (122)	...	Poor	Pitting	253
444	S44400	As received, spot welded	...	6	50	72 h	16 (632)	Crevice maximum under rubber band .37 (15)	190
444	S44400	HT 750°C/30 min, tempered 600°C/1 h, WQ spot welded	...	6	50	72 h	11 (430)	Crevice maximum under rubber band .35 (14)	190

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
444	S44400	HT 750°C/30 min, tempered 600°C/1 h, AC spot welded	...	6	50	72 h	11 (436)	Crevice maximum under rubber band .28 (11)	190
444	S44400	HT 750°C/30 min, tempered 600°C/1 h, FC spot welded	...	6	50	72 h	10 (410)	Crevice maximum under rubber band .12 (5)	190
444	S44400	HT 850°C/30 min, tempered 600°C/1 h, WQ spot welded	...	6	50	72 h	11 (428)	Crevice maximum under rubber band .20 (8)	190
444	S44400	HT 850°C/30 min, tempered 600°C/1 h, AC spot welded	...	6	50	72 h	11 (424)	Crevice maximum under rubber band .14 (6)	190
444	S44400	HT 850°C/30 min, tempered 600°C/1 h, FC spot welded	...	6	50	72 h	10 (404)	Crevice maximum under rubber band .12 (5)	190
444	S44400	HT 960°C/30 min, AC spot welded	...	6	50	72 h	13 (503)	Crevice maximum under rubber band .27 (11)	190
444	S44400	HT 960°C/30 min, FC spot welded	...	6	50	72 h	12 (496)	Crevice maximum under rubber band .27 (11)	190
444	S44400	HT 960°C/30 min, tempered 600°C/1 h, WQ spot welded	...	6	50	72 h	11 (432)	Crevice maximum under rubber band .28 (11)	190
444	S44400	HT 960°C/30 min, tempered 600°C/1 h, AC spot welded	...	6	50	72 h	11 (439)	Crevice maximum under rubber band .26 (10)	190
444	S44400	HT 960°C/30 min, tempered 600°C/1 h, FC spot welded	...	6	50	72 h	11 (420)	Crevice maximum under rubber band .28 (10)	190
444	S44400	HT 960°C/30 min, WQ spot welded	...	6	50	72 h	13 (516)	Crevice maximum under rubber band .35 (14)	190
ALPHA-1	...	...	Rubber band test measuring crevice corrosion. Plain specimen. Average weight loss	10	21.1 (70)	72 h	5.5 (220)	...	98
ALPHA-1	...	...	Rubber band test measuring crevice corrosion. Welded specimen. Average weight loss	10	21.1 (70)	72 h	4.9 (195)	...	98
ALPHA-2	...	...	Rubber band test measuring crevice corrosion. Plain specimen. Average weight loss	10	21.1 (70)	72 h	5.5 (220)	...	98
ALPHA-2	...	...	Rubber band test measuring crevice corrosion. Welded specimen. Average weight loss	10	21.1 (70)	72 h	4.9 (195)	...	98
Carpenter 20	...	...	Chemical processing; slight aeration; rapid agitation. Containing ammonia and fatty acids	...	102 (216)	106 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Field or pilot plant test; slight to moderate aeration; no agitation	~36	25 (77)	61 d	Poor	...	89
F51	S31803	...	...	30	20 (68)	...	Questionable	Pitting	253
F51	S31803	...	...	50	50 (122)	...	Poor	Pitting	253
Ferralium 255	S32550	...	...	10	Room	...	0.625 (25)	...	51
Ferralium 255	S32550	Autogenous welding. GTAW, base metal thickness of 25.4 mm (1.0 in.)	Critical pitting temperature	10	(58)	120 h	...	...	88

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ferralium 255	S32550	GMAW (short arc) base metal thickness of 12.7 mm (0.5 in.)	Critical pitting temperature	10	(77)	120 h	...	...	88
Ferralium 255	S32550	GMAW (short arc), base metal thickness of 3.1 mm (0.125 in.)	Critical pitting temperature	10	30 (86)	120 h	...	...	88
Ferralium 255	S32550	GMAW (short arc), base metal thickness of 6 mm (0.25 in.)	Critical pitting temperature	10	30 (86)	120 h	...	...	88
Ferralium 255	S32550	GMAW (spray), base metal thickness of 9.5 mm (0.375 in.)	Critical pitting temperature	10	(77)	120 h	...	...	88
Ferralium 255	S32550	GMAW (spray), base metal thickness of 12.7 mm (0.5 in.)	Critical pitting temperature	10	(77)	120 h	...	...	88
Ferralium 255	S32550	GTAW, base metal thickness of 12.7 mm (0.5 in.)	Critical pitting temperature	10	(77)	120 h	...	...	88
Ferralium 255	S32550	GTAW, base metal thickness of 3.1 mm (0.125 in.)	Critical pitting temperature	10	(77)	120 h	...	...	88
Ferralium 255	S32550	Mill-annealed at 1038°C (1900°F). Annealing treatment: 482°C (900°F), 1 h, water quenched	...	10	Room	...	0.23 (9)	...	88
Ferralium 255	S32550	Mill-annealed at 1038°C (1900°F). Annealing treatment: 927°C (1700°F), 1 h, water quenched	...	10	Room	...	10 (400)	...	88
Ferralium 255	S32550	Mill-annealed at 1038°C (1900°F). Annealing treatment: 1260°C (2300°F), 30 min, water quenched	...	10	Room	...	11.3 (450)	...	88
Ferralium 255	S32550	Mill-annealed at 1038°C (1900°F). Annealing treatment: 1260°C (2300°F), 30 min, water quenched plus 1038° (1900°F), 20 min, water quenched	...	10	Room	...	0 (0)	...	88
Ferralium 255	S32550	Mill-annealed at 1038°C (1900°F), water quenched	...	10	Room	...	11.3 (450)	...	88
Ferralium 255	S32550	Reannealed at 1038°C (1900°F), water quenched	Critical pitting temperature	10	40 (104)	120 h	...	...	88
Ferralium 255	S32550	SMAW, base metal thickness of 12.7 mm (0.5 in.)	Critical pitting temperature	10	30 (86)	120 h	...	...	88
Ferralium 255	S32550	SMAW, base metal thickness of 3.1 mm (0.125 in.)	Critical pitting temperature	10	30-35 (86-94)	120 h	...	...	88
Ferralium 255	S32550	SMAW, base metal thickness of 6.4 mm (0.25 in.)	Critical pitting temperature	10	30 (86)	120 h	...	...	88

Stainless Steels: Crevice Corrosion Data in 10% Ferric Chloride

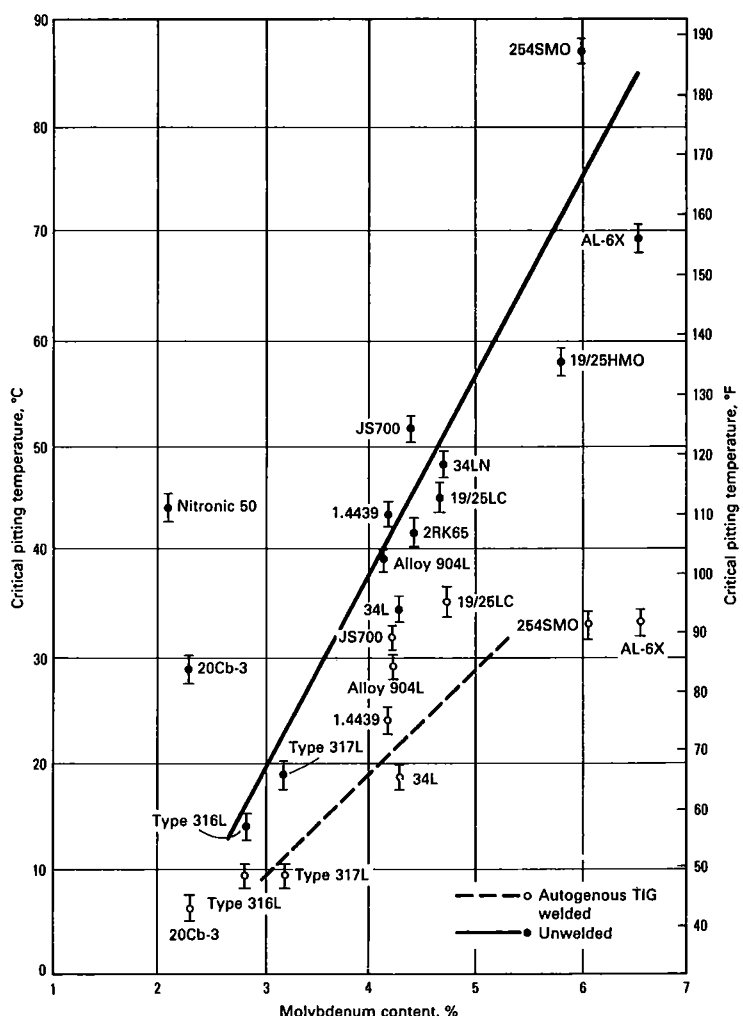
Alloy	Temperature at onset of crevice corrosion
AL 2205	20 °C (68 °F)
AL 29-4C	52 °C (125 °F)
AL 6XN	45 °C (113 °F)
AL 904L	18 °C (65 °F)
Alloy 625	45 °C (113 °F)
Altemp 625	40-45 °C (104-113 °F)
E-Brite	24 °C (75 °F)
Type 316	-3 °C (27 °F)
Type 317	2 °C (35 °F)

Note: ASTM Procedure G-48 using a 10% ferric chloride solution.
Source: Ref 120

Nickel Alloys: Critical Pitting Temperature

Alloy	Critical pitting temperature, °C
825	0.0, 0.0
904L	2.5, 5.0
Type 317LM stainless steel	2.5, 2.5
G	23.0, 25.0
G-3	25.0, 25.0
C-4	37.5, 37.5
625	35.0, 40.0
ALLCORR	52.5, 52.5
C-276	60.0, 65.0
C-22	70.0, 70.0

Note: Alloys evaluated in 6% ferric chloride for 24-h periods
Source: Ref 123



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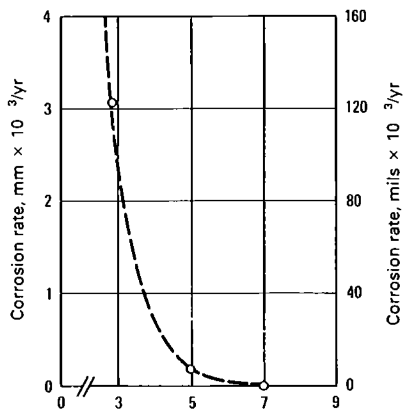
Austenitic stainless steels. Critical pitting temperature vs. molybdenum content of commercial austenitic steels after testing in 10% $FeCl_3$. Resistance to pitting corrosion, as measured by critical pitting temperature, increases with molybdenum content and decreases after autogenous gas tungsten arc welding. Source: A. Garner, "How Stainless Steel Welds Corrode," *Metal Progress*, Vol 27, Apr 1985, 32.

Heat- and Corrosion-Resistant Alloys: Comparative Crevice Corrosion Data in 6% Ferric Chloride

Alloy	Temperature at onset of crevice corrosion
Cabot alloy No. 625	45 °C
Hastelloy alloy G	30 °C
Source: Ref 67	



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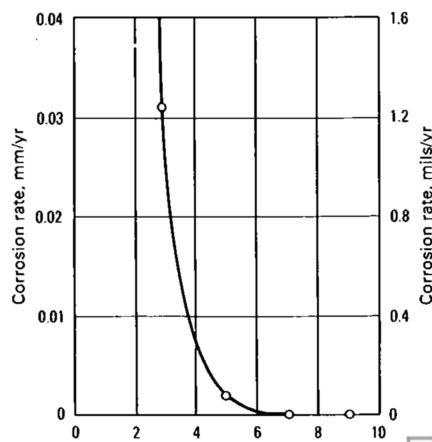
Metallic glass. Corrosion rates of metallic glasses of Ni-Cr-$P_{15}B_5$ in 10 wt% $FeCl_3{\cdot}6H_2O$ at 30 °C (85 °F) vs. chromium content. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 867.



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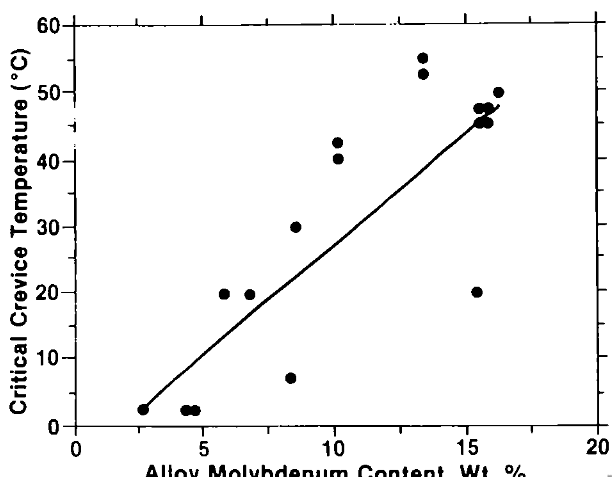
Amorphous nickel-chromium alloys. Effect of chromium content on the corrosion rates of amorphous Ni-Cr-$P_{15}B_5$ alloys in 10% $FeCl_3{\cdot}6H_2O$ at 30 ± 1 °C (85 ± 2 °F). The corrosion rate was estimated from weight loss during immersion for 168 h. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 866.



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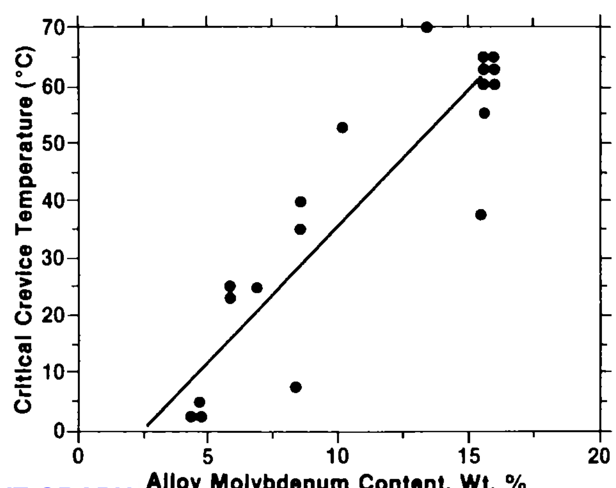
Nickel alloys. Critical crevice temperature for nickel alloys in 6% $FeCl_3$ determined by the modified MTI procedure. Source: E.L. Hibner, "Modification of Critical Crevice Temperature Test Procedures for Nickel-Alloys in a Ferritic Chloride Environment," *Materials Performance*, Vol 26, Mar 1987, 38.



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Nickel alloys. Critical crevice temperature for nickel alloys in 6% $FeCl_3$ determined by the MTI procedure. Source: E.L. Hibner, "Modification of Critical Crevice Temperature Test Procedures for Nickel-Alloys in a Ferritic Chloride Environment," *Materials Performance*, Vol 26, Mar 1987, 38.

Ferric Nitrate

Colorless to pale violet crystals, soluble in water and alcohol, ferric nitrate melts at 47.2 °C and decomposes above 125 °C. Used in dyeing, tanning, and chemistry, it is a strong oxidant and irritant, and a fire hazard when in contact with organic substances

Corrosion Behavior of Various Metals and Alloys in Ferric Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253

Ferric Phosphate

Also known as iron phosphate, $FePO_4 \cdot 2H_2O$, is a yellow-white powder, very slightly soluble in water and soluble in acids, which is decomposed by heat and is used as a fertilizer and food additive.

Corrosion Behavior of Various Metals and Alloys in Ferric Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	98 (208)	...	Resistant	...	253
302	S30200	...	...	...	98 (208)	...	Resistant	...	253
303	S30300	...	...	...	98 (208)	...	Resistant	...	253
303	S30300	...	...	...	98 (208)	...	Resistant	...	253
304	S30400	...	...	...	98 (208)	...	Resistant	...	253
304L	S30403	...	...	...	98 (208)	...	Resistant	...	253
304LN	S30453	...	...	...	98 (208)	...	Resistant	...	253
316	S31600	...	...	...	98 (208)	...	Resistant	...	253
316F	S31620	...	...	...	98 (208)	...	Resistant	...	253
316L	S31603	...	...	...	98 (208)	...	Resistant	...	253
316LN	S31653	...	...	...	98 (208)	...	Resistant	...	253
316Ti	S31635	...	...	...	98 (208)	...	Resistant	...	253
317L	S31703	...	...	...	98 (208)	...	Resistant	...	253
317LN	S31725	...	...	...	98 (208)	...	Resistant	...	253
321	S32100	...	...	...	98 (208)	...	Resistant	...	253
329	S32900	...	...	...	98 (208)	...	Resistant	...	253
347	S34700	...	...	...	98 (208)	...	Resistant	...	253
403	S40300	...	...	...	98 (208)	...	Good	...	253
405	S40500	...	...	...	98 (208)	...	Good	...	253
409	S40900	...	...	...	98 (208)	...	Good	...	253
410	S41000	...	...	...	98 (208)	...	Good	...	253
416	S41600	...	...	...	98 (208)	...	Good	...	253
420	S42000	...	...	...	98 (208)	...	Good	...	253
430	S43000	...	...	...	98 (208)	...	Resistant	...	253
434	S43400	...	...	...	98 (208)	...	Resistant	...	253
F51	S31803	...	...	...	98 (208)	...	Resistant	...	253

Ferric Sulfate

Ferric sulfate, $Fe_2(SO_4)_3 \cdot 9H_2O$, also known as iron sulfate, is a deliquescent solid composed of yellow rhombohedral crystals. It is soluble in water and decomposes when heated. Ferric sulfate is used as a disinfectant, a pigment, a soil conditioner, and as a chemical intermediate and analytical reagent.

Corrosion Behavior of Various Metals and Alloys in Ferric Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
Lead	L50045	...	...	10-20	24-79 (75-175)	...	0.05 (2) max	...	95
Magnesium alloy AZ61A	M11610	Specimen size, 75 × 25 × 1.5 mm (3 × 1 × 0.06 in.); surface preparation, HNO_3 pickling	Volume of testing solution, 100 ml. Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	5.8 (230)	...	12
Nickel and alloys									
Inco C-276	N10276	Unwelded, solution heat treated specimens	Corrosion test ASTM G28	...	...	...	5.69 (224)	...	40
Inco C-276	N10276	As-welded with the gas-tungsten-arc method	Corrosion test ASTM G28	...	...	...	6.93 (273)	...	40
Refractory metals and alloys									
Titanium	...	...	...	10	Room	...	Resistant	...	90
Zr702	R60702	...	...	10	0-100 (32-212)	...	0.05 (2) max	...	15
Stainless steels									
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	50	21 (70)	...	Good	...	121
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Containing ferric oxide slurry and water	5	18 (65)	32 d	0.003 (0.1) max	...	89
304	S30400	...	Metal processing (pickling); field or pilot plant test; rapid agitation. Plus 0.5% citric acid; copper ions present	10	77-99 (170-210)	38 d	0.01 (0.4)	Crevice attack	89
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	50	21 (70)	...	Good	...	121
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Containing ferric oxide slurry and water	5	18 (65)	32 d	0.003 (0.1) max	...	89
316	S31600	...	Metal processing (pickling); field or pilot plant test; rapid agitation. Plus 0.5% citric acid; copper ions present	10	77-99 (170-210)	38 d	0.003 (0.1)	Crevice attack	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Containing ferric oxide slurry and water	5	18 (65)	32 d	0.003 (0.1) max	...	89
410	S41000	...	...	10	21 (70)	...	Good	...	121

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferric Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	50	21 (70)	...	Good	...	121
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	50	21 (70)	...	Good	...	121
430	S43000	Nonsensitized sample. Heat treated at 760°C (1400°F) 1 h, water quenched	Plus 50% H_2SO_4	...	...	...	3.7 (148)	Intergranular corrosion	41
430	S43000	Sensitized sample. Heat treated at 1093°C (2000°F) 1 h, air cool	Plus 50% H_2SO_4	...	...	...	110 (4400)	Intergranular corrosion	41
Carpenter 20	...	Cast specimens	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Containing ferric oxide slurry and water	5	18 (65)	32 d	0.003 (0.1) max	...	89
Carpenter 20	...	Cast specimens	Metal processing (pickling); field or pilot plant test; rapid agitation. Plus 0.5% citric acid; copper ions present	10	77-99 (170-210)	38 d	Resistant	...	89

Ferrous Chloride

Ferrous chloride, $FeCl_2·4H_2O$, also known as iron chloride and iron dichloride, is a green-blue deliquescent crystalline solid. It is soluble in water and alcohol and is used as a mordant in the dyeing of textiles. Ferrous chloride finds use in sewage treatment, in metallurgy, and in pharmaceutical preparations.

Corrosion Behavior of Various Metals and Alloys in Ferrous Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferrous Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	10-30	24 (75)	...	0.5 (1.25)	...	95
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.03 (1)	Severe pitting; crevice attack	89
Refractory metals and alloys									
Titanium	...	...	Plus 0.5% HCl	30	79 (175)	...	0.006 (0.24)	...	90
Titanium	...	...	Plus 0.5% HCl	30	79 (175)	...	0.006 (0.24)	...	90
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Saturated ferrous chloride water solution, plus 0.09% hydrochloric acid (evaporator)	...	135 (275)	1 d	0.12 (4.6)	...	89
316	S31600	...	Chemical processing (evaporation); lab test; no aeration; rapid agitation. Plus 0.07-2.5 g/L lead ion, 0.07 g/L tin ion as chlorides, pH 1.2	~16.5	66 (150)	1.75 d	0.15 (6)	...	89
316	S31600	...	Chemical processing (evaporation); lab test; no aeration; rapid agitation. Plus 0.07-2.5 g/L lead ion, 0.07 g/L tin ion as chlorides, pH 1.2	~16.5	66 (150)	1.75 d	2 (80)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Saturated ferrous chloride water solution, plus 0.09% hydrochloric acid (evaporator)	...	135 (275)	1 d	0.14 (5.4)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.04 (1.7)	Severe pitting; crevice attack	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation; sensitized specimens. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.07 (2.9)	Severe pitting; crevice attack	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation; low-carbon grade (0.03% C max) specimens. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.04 (1.7)	Moderate pitting; crevice attack	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.04 (1.4)	Severe pitting; crevice attack	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 5% organic wastes, 3% resorcinol, 0.5% hydrochloric acid, abrasive iron residue, pH 1 (filter press)	30	79 (175)	10 d	0.03 (1.2)	Severe pitting; crevice attack	89
Carpenter 20	...	Cast specimens	Chemical processing (evaporation); lab test; no aeration; rapid agitation. Plus 0.07-2.5 g/L lead ion, 0.07 g/L tin ion as chlorides, pH 1.2	~16.5	66 (150)	1.75 d	0.1 (4)	...	89
Carpenter 20	...	Cast specimens	Chemical processing (evaporation); lab test; no aeration; rapid agitation. Plus 0.07-2.5 g/L lead ion, 0.07 g/L tin ion as chlorides, pH 1.2	~16.5	66 (150)	1.75 d	1.0 (39)	...	89

Ferrous Sulfate

Ferrous sulfate, $FeSO_4 \cdot 7H_2O$, also known as ferrisulpas, green copperas, green vitriol, iron sulfate, and melanterite, is composed of blue-green monoclinic crystals. It is soluble in water and is used as a mordant for dyeing wool in the textile industry. Ferrous sulfate is also used as a disinfectant and in the manufacture of ink.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Solid ferrous sulfate had no effect on aluminum alloy 3003, but mildly attacked (around 4 mils/yr) aluminum alloy 5154 in laboratory test conditions of ambient temperature and 100% relative humidity. Aqueous solutions of 0.001 to 10% ferrous sulfate mildly attacked (around 3 mils/yr) aluminum alloy 1100 in other tests at ambient temperature. Ferrous sulfate oxidizes at elevated temperatures to ferric sulfate, which is corrosive to aluminum alloys. Ferrous sulfate solutions have been handled in aluminum alloy A356.0 valves and aluminum spray tanks.

Corrosion Behavior of Various Metals and Alloys in Ferrous Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	10	24-100 (75-212)	...	0.5 (20) max	...	95
Platinum	P04995	...	...	All	Room	...	0.05 (2) max	...	5
Silver	P07010	...	Attacked upon heating	All	Room	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferrous Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 16-18% ferric sulfate, 10% sodium chloride, 0.5-1% sodium hypochlorite, trace hydrochloric acid (cypress tank)	20	95 (203)	1.8 d	4.83 (190)	Severe pitting	89
304	S30400	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus some wetting agents, pH 2.5 (evaporator crystallizer)	16	82-98 (180-210)	16 d	0.015 (0.6)	Severe pitting; crevice attack	89
304	S30400	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus trace of wetting agents, pH 2.5 (evaporator crystallizer)	24	32-54 (90-130)	16 d	0.003 (0.1)	Crevice attack	89
304	S30400	...	Metal processing; field or pilot plant test; no aeration; no agitation. With carbon over the standard maximum. Plus 19.5% sulfuric acid, 10% titanium dioxide as sulfate, 2-3% solids, 1.7 g/L titanium ion as sulfate, trace hydrogen sulfide (Dorr settling tank)	20	50-70 (122-158)	1 d	130 (5120)	...	89
304	S30400	...	Metal processing; field or pilot plant test; strong aeration; rapid agitation. Plus 5% sulfuric acid, 5% hydrofluoric acid	10	48 (120)	1.7 d	9.98 (393)	...	89
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 16-18% ferric sulfate, 10% sodium chloride, 0.5-1% sodium hypochlorite, trace hydrochloric acid (cypress tank)	20	95 (203)	1.8 d	1.8 (70)	Severe pitting; crevice attack	89
316	S31600	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus trace of wetting agents, pH 2.5 (evaporator crystallizer)	24	32-54 (90-130)	16 d	0.003 (0.1)	Crevice attack	89
316	S31600	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus some wetting agents, pH 2.5 (evaporator crystallizer)	16	82-98 (180-210)	16 d	0.008 (0.3)	Crevice attack	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferrous Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Metal processing; field or pilot plant test; no aeration; no agitation. With carbon over the standard maximum. Plus 19.5% sulfuric acid, 10% titanium dioxide as sulfate, 2-3% solids, 1.7 g/L titanium ion as sulfate, trace hydrogen sulfide (Dorr settling tank)	20	50-70 (122-158)	1 d	300 (11500)	Slight pitting; crevice attack	89
316	S31600	...	Metal processing; field or pilot plant test; strong aeration; rapid agitation. Plus 5% sulfuric acid, 5% hydrofluoric acid	10	48 (120)	1.7 d	4.9 (191)	...	89
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
403	S40300	...	...	10	20 (68)	...	Resistant	...	253
403	S40300	...	...	10	Boiling	...	Good	...	253
405	S40500	...	...	10	20 (68)	...	Resistant	...	253
405	S40500	...	...	10	Boiling	...	Good	...	253
409	S40900	...	...	10	20 (68)	...	Resistant	...	253
409	S40900	...	...	10	Boiling	...	Good	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	10	20 (68)	...	Resistant	...	253
410	S41000	...	...	10	Boiling	...	Good	...	253
416	S41600	...	...	10	20 (68)	...	Resistant	...	253
416	S41600	...	...	10	Boiling	...	Good	...	253
420	S42000	...	...	10	20 (68)	...	Resistant	...	253
420	S42000	...	...	10	Boiling	...	Good	...	253
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Good	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Poor	...	120
Carpenter 20	...	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation; cast specimen. Plus 16-18% ferric sulfate, 10% sodium chloride, 0.5-1% sodium hypochlorite, trace hydrochloric acid (cypress tank)	20	95 (203)	1.8 d	1.3 (50)	Severe pitting; crevice attack	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Ferrous Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus trace of wetting agents, pH 2.5 (evaporator crystallizer)	24	32-54 (90-130)	16 d	0.003 (0.1)	...	89
Carpenter 20	...	...	Metal processing (pickling); field or pilot plant test; no aeration; rapid agitation. Plus some wetting agents, pH 2.5 (evaporator crystallizer)	16	82-98 (180-210)	16 d	0.005 (0.2)	...	89
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253

Fertilizers

Fertilizers are composed of many compounds, either in liquid or solid form. They are also stored, transported and applied in diluted and undiluted condition. Some typical compositions of concentrated suspensions or salts of industrial fertilizers before dilution are presented below:

In laboratory tests, the corrosive effects of fertilizers on aluminum alloys vary greatly with some being compatible and others very corrosive. Generally, the solid and liquid nitrogen fertilizers have been the least corrosive, while the complete mix neutral fertilizers have been the most corrosive. Aluminum alloy equipment has been used in the manufacture and handling of the nitrogen fertilizers.

Carbon steels can be quite resistant to many fertilizers but can be attacked by others, for example, urea. In liquid ammonia, steels may suffer stress corrosion cracking unless small amounts of water are present.

Ammonium orthophosphate suspension	10%N, 30%P_2O_5, 2% suspending agent, 1%MgO, 0.3%F, 0.06%CaO, traces of Fe, Al, SiO_2
Ammonium sulphate	21%N, 0.05% free SO_3
Clear ammonium orthophosphate solution	6%N, 20.5%P_2O_3
Monoammonium phosphate	11%N, 50%P_2O_5, 2%MgO, 0.5%F, 0.1%CaO, traces of Fe, Al, SiO_2
Phosphoric acid	50%P_2O_5, 4.5%SO_4, 2%MgO, 0.5%F, 0.1%CaO
Potassium chloride	60.1%K_2O, 0.9%$MgSO_4$, 0.8%MgO, 0.8%$MgCl_2$, 2.2%NaCl, 0.2%$CaSO_4$, 13%N, 38%K
Potassium nitrate	13%N, 38%K
Potassium sulphate	52.1%K_2O, 1.7%$MgSO_4$, 0.6%MgO, 0.3%NaCl, 0.3%Cl
Urea	46%N, (≤1%$NH(CONH_2)_2$), 0.3% formaldehyde
Urea ammonium nitrate	32%N (16% urea nitrogen, 8% ammonium nitrogen, 8% nitrate)
Urea phosphate	14%N, 34%P_2O_5, 0.5%MgO, 0.35%F, 0.07%CaO
Zinc sulphate	22%Zn, traces of Cu

Corrosion Behavior of Various Metals and Alloys in Fertilizers

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
1020	G10200	...	Liquid; 10-10-5 with NH_4NO_3	...	38-57 (100-135)	28 d	.094 (3.7)	...	251
1020	G10200	...	Liquid; 10-10-5 with urea	...	38-57 (100-135)	28 d	.037 (1.4)	...	251
1020	G10200	...	Liquid; 10-10-5 with urea	...	38-57 (100-135)	28 d	.067 (2.6)	...	251
1020	G10200	...	Liquid; 3-9-9	...	38-57 (100-135)	28 d	.094 (3.7)	...	251

(Continued)

Corrosion Behavior of Various Metals and Alloys in Fertilizers (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
1020	G10200	...	Liquid; 6-6-6 with NH_4NO_2	...	38-57 (100-135)	28 d	.20 (7.9)	...	251
1020	G10200	...	Liquid; 6-6-6 with urea	...	38-57 (100-135)	28 d	.064 (2.5)	...	251
1020	G10200	...	Liquid; 6-6-6 with urea	...	38-57 (100-135)	28 d	.085 (3.4)	...	251
1020	G10200	...	Liquid; 8-24-0	...	38-57 (100-135)	28 d	.16 (6.2)	...	251
5 Cr	K51545	...	Liquid; 10-10-5 with NH_4NO_3	...	38-57 (100-135)	28 d	.21 (8.2)	...	251
5 Cr	K51545	...	Liquid; 10-10-5 with urea	...	38-57 (100-135)	28 d	.012 (0.5)	...	251
5 Cr	K51545	...	Liquid; 10-10-5 with urea	...	38-57 (100-135)	28 d	.012 (0.5)	...	251
5 Cr	K51545	...	Liquid; 3-9-9	...	38-57 (100-135)	28 d	.36 (14)	...	251
5 Cr	K51545	...	Liquid; 6-6-6 with NH_4NO_2	...	38-57 (100-135)	28 d	.15 (5.9)	...	251
5 Cr	K51545	...	Liquid; 6-6-6 with urea	...	38-57 (100-135)	28 d	.024 (1.0)	...	251
5 Cr	K51545	...	Liquid; 6-6-6 with urea	...	38-57 (100-135)	28 d	.015 (0.6)	...	251
5 Cr	K51545	...	Liquid; 8-24-0	...	38-57 (100-135)	28 d	.003 (0.1)	...	251

Flue Gas

Flue gas environments are actually complex mixtures of many constituents, often containing various forms of sulfur and nitrogen bearing gases. The presence of moisture and the variation of temperature create a myriad of conditions that are difficult to list singly in a table of corrosive compounds. Therefore, much work has been done on the resistance of metals and alloys to environments referred to in the corrosion literature as flue gas or flue gas desulfurization systems. These systems may also contain slurries of chlorides, fluorides and flyash.

The many wet scrubbing process systems utilize liquids or slurries ranging from available local water to both alkaline and acid chemical solutions to contact the gas and achieve absorption of the SO_2. During absorption of the SO_2, and any small amounts of SO_3, all of the scrubbing media acquire acidity, and the pH of the scrubbing liquor is almost always lowered to less than 7. The scrubbing liquors also contain chloride ions introduced from the fuel (especially coal) and the water and chemicals used in making up the scrubbing solutions. Since water pollution regulations usually preclude dumping the scrubbing liquor, closed loop recirculation of the liquid results in considerable buildup of soluble chlorides and other contaminants. The resultant acid chloride solutions can be quite corrosive.

The corrosivity of the flue gases to aluminum alloys and steels depends on the sulfur content of the fuel being burned and if condensation is present. The sulfur content of fuels increases in the following order: processed natural gas, fuel oil, hard coal, soft coal. Aluminum alloy flue liners have been widely used for house chimneys. Generally, aluminum alloys will suffer corrosion if condensation is present in the flue. In the presence of moisture, stainless steel and nickel base alloys are often required to resist corrosion.

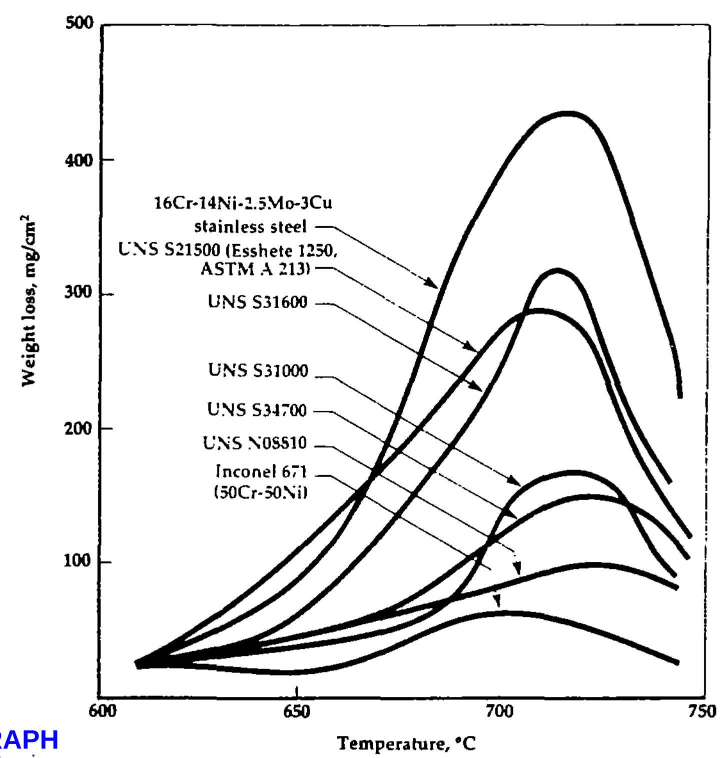
Corrosion Behavior of Various Metals and Alloys in Flue Gas

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Alloy 625	N06625	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 8 (.20) Crevice 0.4 (.01)	256
Alloy 625	N06625	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 4 (0.1) max Crevice 6.7 (.17)	256
Alloy 625	N06625	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 30 (0.75) Crevice 39 (1.0)	256
Alloy C276	N10276	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 14 (.35) Crevice 0.4 (.01)	256
Alloy C276	N10276	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 4 (0.1) max Crevice 6 (.15)	256
Alloy C276	N10276	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 4 (0.1) max Crevice 12 (0.3)	256

(Continued)

Corrosion Behavior of Various Metals and Alloys in Flue Gas (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy G	N06007	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 17 (.43) Crevice 5 (.12)	256
Alloy G	N06007	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 4 (0.1) max Crevice 14 (.35)	256
Alloy G	N06007	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 126 (3.2) Crevice 75 (1.9)	256
Stainless steels									
316	S31600	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 11 (.28) Crevice 18 (.46)	256
316	S31600	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 20 (0.5) Crevice 30 (0.75)	256
316	S31600	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 6(.14) Crevice 4(.09)	256
317LM	S31725	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 4(0.1) max Crevice 16 (.40)	256
317LM	S31725	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 55 (1.4) Crevice 39 (1.0)	256
317LM	S31725	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 12(.32) Crevice 11 (.29)	256
904L	N08904	...	Scrubber environment, in absorber, pH 5.2, 21,000 ppm chlorides	...	55 (131)	90 d	...	Pits 4 (.01) max Crevice 24 (.60)	256
904L	N08904	...	Scrubber environment, outlet duct pre-heat, pH 2.0, 1400 ppm chlorides	...	58 (136)	90 d	...	Pits 71 (1.8) Crevice35 (0.9)	256
904L	N08904	...	Scrubber environment. Wet-dry zone at inlet	...	55 (131)	90 d	...	Pits 12 (.32) Crevice 10 (.25)	256



LIVE GRAPH
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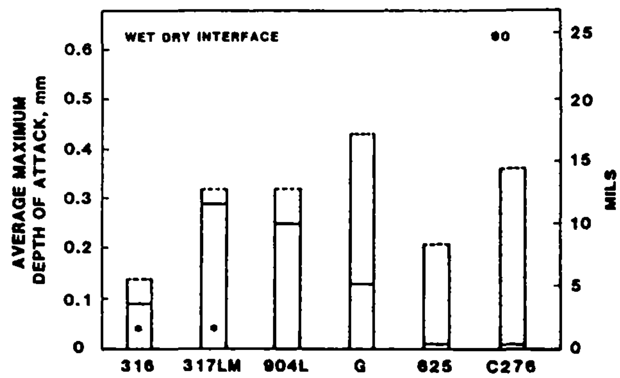
Various alloys. Corrosion rates of alloys in a laboratory test using synthetic ash and flue gas. Exposure time was 50 h. Ref. 271



Various alloys. Comparison of the average maximum depths of bold surface and crevice attack on six baseline alloys exposed in the wet-dry interface of flue gas desulfurization environment for 90 days. In each bar, the solid line represents average maximum depth of crevice attack associated with the mounting washer but not occurring directly beneath it; the dashed line denotes maximum depth of pitting on the bold surface. Asterisks indicate SCC. Ref. 289

Fluorine

Fluorine (F) is a chemical element (group VIIa, halogens) that melts at −219.62 °C and boils at −188.1 °C. It is a pale yellow, highly toxic, corrosive, flammable gas. It is the most electronegative of all elements and the most chemically energetic of all nonmetallic elements.

Fluorine is a high-tonnage chemical that is used in production of fluorides, in synthesis of fluorocarbons, and as an oxidizer for rocket fuels. Because of its severe oxidizing characteristics, special permits are required for shipping of fluorine, and all containers, piping, and processing equipment used for fluorine service must be passivated prior to use. Thereafter, they must be designated for exclusive fluorine service.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests, aluminum 1100 alloy was resistant to fluorine at temperatures up to 450 °C (842 °F). In the presence of moisture, hydrofluoric acid is formed, which corrodes aluminum alloys. Dry fluorine gas has been handled in aluminum alloy equipment. A durable protective coating is formed on the aluminum surfaces contacting the gas.

Stainless Steels. At lower temperatures, most austenitic stainless steels resist fluorine gas if the gas is completely dry. The presence of even small amounts of moisture results in accelerated attack, especially pitting and possibly stress-corrosion cracking.

Nickel Alloys. Although fluorine and chlorine are strong oxidizers that react with metal, Nickel 200 can be used successfully in such environments under certain conditions. At room temperature, Nickel 200 forms a protective fluoride film and is considered satisfactory for handling fluorine at low temperatures. At elevated temperatures, Nickel 201 is preferred.

Magnesium. Dry fluorine causes little or no corrosion of magnesium at room or slightly elevated temperatures. The presence of a small amount of water causes negligible attack by fluorine.

Niobium. Niobium is an important metal for chromium plating applications. It is particularly attractive when fluoride ions are also present. It has the highest resistance to attack by fluoride ions among reactive and refractory metals.

Gold. Dry fluorine can be handled by gold, within limitations.

Silver. Silver is not resistant to fluorine unless it is cathodically protected.

Tantalum. Fluorine attacks tantalum at room temperature.

Tin. Reactions of fluorine with tin become significant only at temperatures above 100 °C (212 °F).

Corrosion Behavior of Various Metals and Alloys in Fluorine

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	Dry	...	500 (930)	...	.05 (2)	...	250
Silver	P07010	...	Dry	...	22 (72)	...	Good	...	250
Nickel and alloys									
Nickel 201	N02201	...	Dry	...	400 (752)	...	0.2 (8.4)	...	44
Nickel 201	N02201	...	Dry	...	450 (842)	...	0.6 (22.8)	...	44
Nickel 201	N02201	...	Dry	...	500 (932)	...	1.6 (61.2)	...	44
Nickel 201	N02201	...	Dry	...	600 (1112)	...	9 (348)	...	44
Nickel 201	N02201	...	Dry	...	650 (1202)	...	5 (192)	...	44
Nickel 201	N02201	...	Dry	...	700 (1292)	...	10 (408)	...	44
Refractory metals and alloys									
Titanium	...	...	...	5-20	Elevated	...	Poor	...	90
Titanium	...	...	Commercial	Gas	Gas-109 (229)	...	0.9 (35)	...	90
Titanium	...	...	Commercial	Liquid	Gas-109 (229)	...	0.9 (35)	...	90
Titanium	...	...	HF free	Liquid	Gas-196 (385)	...	0.011 (0.44)	...	90
Titanium	...	...	HF free	Gas	Gas-196 (385)	...	0.011 (0.44)	...	90
Stainless steels									
304	S30400	...	Gas	100	...	...	Resistant	...	121
316	S31600	...	Gas	100	...	...	Resistant	...	121
430	S43000	...	Gas	100	...	...	Resistant	...	121
410	S41000	...	Gas	100	...	...	Poor	...	121

Fluosilicic Acid

Fluosilicic acid, H_2SiF_6, also known as hydrofluorosilicic acid, is a colorless liquid that is soluble in water. It is highly corrosive and toxic, attacking glass and stoneware. Fluosilicic acid is used in water fluoridation, electroplating, and in manufacturing enamels and cement.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Lead. The corrosion rates of chemical lead and 6% antimonial lead in fluosilicic acid decrease with the addition of sulfuric acid.

Corrosion Behavior of Various Metals and Alloys in Fluosilic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Chemical lead	L51120	...	...	10	45 (113)	...	1.6 (64)	...	254
Chemical lead	L51120	...	...	5	45 (113)	...	1.3 (53)	...	254
Chemical lead	L51120	...	With 1% sulfuric acid	10	45 (113)	...	2.2 (88)	...	254
Chemical lead	L51120	...	With 10% sulfuric acid	10	45 (113)	...	0.1 (4)	...	254
Chemical lead	L51120	...	With 5% sulfuric acid	5	45 (113)	...	0.2 (9)	...	254
Lead	L50045	...	...	10	45 (113)	...	1.3 (50) min	...	95
Lead, 6% antimonial	L53110	...	...	10	45 (113)	...	2.9 (115)	...	130
Lead, 6% antimonial	L53110	...	...	10	45 (113)	...	2.9 (115)	...	254

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Corrosion Behavior of Various Metals and Alloys in Fluosilic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead, 6% antimonial	L53110	...	...	5	45 (113)	...	2 (77)	...	130
Lead, 6% antimonial	L53110	...	...	5	45 (113)	...	1.9 (77)	...	254
Lead, 6% antimonial	L53110	...	Plus 1% H_2SO_4	10	45 (113)	...	1.9 (76)	...	130
Lead, 6% antimonial	L53110	...	Plus 10% H_2SO_4	1	45 (113)	...	0.2 (9)	...	130
Lead, 6% antimonial	L53110	...	Plus 5% H_2SO_4	5	45 (113)	...	0.4 (14)	...	130
Lead, 6% antimonial	L53110	...	With 1% sulfuric acid	10	45 (113)	...	1.9 (76)	...	254
Lead, 6% antimonial	L53110	...	With 10% sulfuric acid	10	45 (113)	...	0.2 (9)	...	254
Lead, 6% antimonial	L53110	...	With 5% sulfuric acid	5	45 (113)	...	0.4 (14)	...	254
Lead, chemical	L51120	...	...	1	45 (113)	...	0.1 (4)	...	130
Lead, chemical	L51120	...	...	10	45 (113)	...	1.6 (64)	...	130
Lead, chemical	L51120	...	...	5	45 (113)	...	1.3 (53)	...	130
Lead, chemical	L51120	...	Plus 1% H_2SO_4	10	45 (113)	...	2.2 (88)	...	130
Lead, chemical	L51120	...	Plus 5% H_2SO_4	5	45 (113)	...	0.2 (9)	...	130
Magnesium	...	...	...	All	Room	...	Poor	...	119
Silver	P07010	...	...	...	65 (150)	...	0.05 (2) max	...	4
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation	20	57 (135)	38 d	0.13 (5)	...	89
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation Plus some hydrofluoric and phosphoric acids	10	60 (140)	19 d	3 (116)	...	89
Refractory metals and alloys									
Titanium	...	...	...	10	Room	...	47.5 (1900)	...	90
Zr702	R60702	...	...	10	Room	...	1.3 (50) min	...	15
Stainless steels									
301	S30100	...	...	Vapors	100 (212)	...	Good	...	253
302	S30200	...	...	Vapors	100 (212)	...	Good	...	253
303	S30300	...	...	Vapors	100 (212)	...	Good	...	253
303	S30300	...	...	Vapors	100 (212)	...	Questionable	...	253
304	S30400	...	...	Vapors	100 (212)	...	Good	...	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation	9.1-23.1	63 (145)	90 d	0.95 (38)	Severe pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation Plus some hydrofluoric and phosphoric acids	10	60 (140)	19 d	Poor	...	89
304L	S30403	...	...	Vapors	100 (212)	...	Good	...	253
304LN	S30453	...	...	Vapors	100 (212)	...	Good	...	253
316	S31600	...	...	Vapors	100 (212)	...	Good	...	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation	22	63 (145)	94 d	0.05 (2)	Severe pitting; crevice attack	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation	9.1-23.1	63 (145)	90 d	0.13 (5)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus some hydrofluoric and phosphoric acids	10	60 (140)	19 d	0.6 (24)	...	89

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Fluosilic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	...	Vapors	100 (212)	...	Good	...	253
316L	S31603	...	...	Vapors	100 (212)	...	Good	...	253
316L	S31603	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation	20	57 (135)	38 d	0.13 (5)	...	89
316LN	S31653	...	...	Vapors	100 (212)	...	Good	...	253
316Ti	S31635	...	...	Vapors	100 (212)	...	Good	...	253
317	S31700	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation	20	57 (135)	38 d	0.13 (5)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus some hydrofluoric and phosphoric acids	10	60 (140)	19 d	3 (130)	...	89
317L	S31703	...	...	Vapors	100 (212)	...	Good	...	253
317LN	S31725	...	...	Vapors	100 (212)	...	Good	...	253
321	S32100	...	...	Vapors	100 (212)	...	Good	...	253
329	S32900	...	...	Vapors	100 (212)	...	Good	...	253
347	S34700	...	...	Vapors	100 (212)	...	Good	...	253
403	S40300	...	...	Vapors	100 (212)	...	Poor	...	253
405	S40500	...	...	Vapors	100 (212)	...	Poor	...	253
409	S40900	...	...	Vapors	100 (212)	...	Poor	...	253
410	S41000	...	...	Vapors	100 (212)	...	Poor	...	253
416	S41600	...	...	Vapors	100 (212)	...	Poor	...	253
420	S42000	...	...	Vapors	100 (212)	...	Poor	...	253
430	S43000	...	...	Vapors	100 (212)	...	Questionable	...	253
434	S43400	...	...	Vapors	100 (212)	...	Good	...	253
Carpenter 20	...	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation	20	57 (135)	38 d	0.08 (3)	Slight pitting	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus some hydrofluoric and phosphoric acids	10	60 (140)	19 d	0.6 (25)	...	89
F51	S31803	...	...	Vapors	100 (212)	...	Good	...	253

Food Products

There are numerous food products that are manufactured, transported and stored in metallic materials. The manufacturing processes and food chemistry are too complex and detailed to describe in this introduction. However, various constituents of these products can cause corrosion of certain metals. For example, lactic acid in milk can be a source of corrosion for some metals. Historically, this is why cans for food containment have been tin plated so as to both avoid corrosion and reduce the contamination of the product with iron. Likewise, aluminum has been successful for containment of carbonated beverages which can be corrosive to unprotected steel, i.e., beer and soda.

Corrosion Behavior of Various Metals and Alloys in Food Products

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Beer	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	Beer	...	70 (158)	...	Resistant	...	253
302	S30200	...	Beer	...	20 (68)	...	Resistant	...	253
302	S30200	...	Beer	...	70 (158)	...	Resistant	...	253
303	S30300	...	Beer	...	20 (68)	...	Resistant	...	253
303	S30300	...	Beer	...	70 (158)	...	Resistant	...	253
304	S30400	...	Beer	...	20 (68)	...	Resistant	...	253
304	S30400	...	Beer	...	70 (158)	...	Resistant	...	253
304L	S30403	...	Beer	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Beer	...	70 (158)	...	Resistant	...	253
304LN	S30453	...	Beer	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Beer	...	70 (158)	...	Resistant	...	253
316	S31600	...	Beer	...	20 (68)	...	Resistant	...	253
316	S31600	...	Beer	...	70 (158)	...	Resistant	...	253
316F	S31620	...	Beer	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Beer	...	70 (158)	...	Resistant	...	253
316L	S31603	...	Beer	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Beer	...	70 (158)	...	Resistant	...	253
316LN	S31653	...	Beer	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Beer	...	70 (158)	...	Resistant	...	253
316Ti	S31635	...	Beer	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Beer	...	70 (158)	...	Resistant	...	253
317L	S31703	...	Beer	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Beer	...	70 (158)	...	Resistant	...	253
317LN	S31725	...	Beer	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Beer	...	70 (158)	...	Resistant	...	253
321	S32100	...	Beer	...	20 (68)	...	Resistant	...	253
321	S32100	...	Beer	...	70 (158)	...	Resistant	...	253
329	S32900	...	Beer	...	20 (68)	...	Resistant	...	253
329	S32900	...	Beer	...	70 (158)	...	Resistant	...	253
347	S34700	...	Beer	...	20 (68)	...	Resistant	...	253
347	S34700	...	Beer	...	70 (158)	...	Resistant	...	253
F51	S31803	...	Beer	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Beer	...	70 (158)	...	Resistant	...	253
301	S30100	...	Buttermilk	...	20 (68)	...	Resistant	...	253
302	S30200	...	Buttermilk	...	20 (68)	...	Resistant	...	253
303	S30300	...	Buttermilk	...	20 (68)	...	Resistant	...	253
303	S30300	...	Buttermilk	...	20 (68)	...	Resistant	...	253
304	S30400	...	Buttermilk	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Buttermilk	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Buttermilk	...	20 (68)	...	Resistant	...	253
316	S31600	...	Buttermilk	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Buttermilk	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Buttermilk	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Buttermilk	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Buttermilk	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Buttermilk	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Buttermilk	...	20 (68)	...	Resistant	...	253
321	S32100	...	Buttermilk	...	20 (68)	...	Resistant	...	253
329	S32900	...	Buttermilk	...	20 (68)	...	Resistant	...	253
347	S34700	...	Buttermilk	...	20 (68)	...	Resistant	...	253
403	S40300	...	Buttermilk	...	20 (68)	...	Good	...	253
405	S40500	...	Buttermilk	...	20 (68)	...	Good	...	253
409	S40900	...	Buttermilk	...	20 (68)	...	Good	...	253
410	S41000	...	Buttermilk	...	20 (68)	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	Buttermilk	...	20 (68)	...	Good	...	253
420	S42000	...	Buttermilk	...	20 (68)	...	Good	...	253
430	S43000	...	Buttermilk	...	20 (68)	...	Resistant	...	253
434	S43400	...	Buttermilk	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Buttermilk	...	20 (68)	...	Resistant	...	253
301	S30100	...	Cheese	...	20 (68)	...	Resistant	...	253
302	S30200	...	Cheese	...	20 (68)	...	Resistant	...	253
303	S30300	...	Cheese	...	20 (68)	...	Resistant	...	253
304	S30400	...	Cheese	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Cheese	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Cheese	...	20 (68)	...	Resistant	...	253
316	S31600	...	Cheese	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Cheese	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Cheese	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Cheese	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Cheese	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Cheese	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Cheese	...	20 (68)	...	Resistant	...	253
321	S32100	...	Cheese	...	20 (68)	...	Resistant	...	253
329	S32900	...	Cheese	...	20 (68)	...	Resistant	...	253
347	S34700	...	Cheese	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Cheese	...	20 (68)	...	Resistant	...	253
301	S30100	...	Chocolate	...	20 (68)	...	Resistant	...	253
302	S30200	...	Chocolate	...	20 (68)	...	Resistant	...	253
303	S30300	...	Chocolate	...	20 (68)	...	Resistant	...	253
303	S30300	...	Chocolate	...	20 (68)	...	Resistant	...	253
304	S30400	...	Chocolate	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Chocolate	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Chocolate	...	20 (68)	...	Resistant	...	253
316	S31600	...	Chocolate	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Chocolate	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Chocolate	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Chocolate	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Chocolate	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Chocolate	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Chocolate	...	20 (68)	...	Resistant	...	253
321	S32100	...	Chocolate	...	20 (68)	...	Resistant	...	253
329	S32900	...	Chocolate	...	20 (68)	...	Resistant	...	253
347	S34700	...	Chocolate	...	20 (68)	...	Resistant	...	253
403	S40300	...	Chocolate	...	20 (68)	...	Resistant	...	253
405	S40500	...	Chocolate	...	20 (68)	...	Resistant	...	253
409	S40900	...	Chocolate	...	20 (68)	...	Resistant	...	253
410	S41000	...	Chocolate	...	20 (68)	...	Resistant	...	253
416	S41600	...	Chocolate	...	20 (68)	...	Resistant	...	253
420	S42000	...	Chocolate	...	20 (68)	...	Resistant	...	253
430	S43000	...	Chocolate	...	20 (68)	...	Resistant	...	253
434	S43400	...	Chocolate	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Chocolate	...	20 (68)	...	Resistant	...	253
301	S30100	...	Cider	...	20 (68)	...	Resistant	...	253
302	S30200	...	Cider	...	20 (68)	...	Resistant	...	253
303	S30300	...	Cider	...	20 (68)	...	Resistant	...	253
304	S30400	...	Cider	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Cider	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Cider	...	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Cider	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Cider	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Cider	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Cider	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Cider	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Cider	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Cider	...	20 (68)	...	Resistant	...	253
321	S32100	...	Cider	...	20 (68)	...	Resistant	...	253
329	S32900	...	Cider	...	20 (68)	...	Resistant	...	253
347	S34700	...	Cider	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Cider	...	20 (68)	...	Resistant	...	253
301	S30100	...	Coffee	...	20 (68)	...	Resistant	...	253
301	S30100	...	Coffee	...	Boiling	...	Resistant	...	253
302	S30200	...	Coffee	...	20 (68)	...	Resistant	...	253
302	S30200	...	Coffee	...	Boiling	...	Resistant	...	253
303	S30300	...	Coffee	...	20 (68)	...	Resistant	...	253
303	S30300	...	Coffee	...	Boiling	...	Resistant	...	253
304	S30400	...	Coffee	...	20 (68)	...	Resistant	...	253
304	S30400	...	Coffee	...	Boiling	...	Resistant	...	253
304L	S30403	...	Coffee	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Coffee	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Coffee	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Coffee	...	Boiling	...	Resistant	...	253
316	S31600	...	Coffee	...	20 (68)	...	Resistant	...	253
316	S31600	...	Coffee	...	Boiling	...	Resistant	...	253
316F	S31620	...	Coffee	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Coffee	...	Boiling	...	Resistant	...	253
316L	S31603	...	Coffee	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Coffee	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Coffee	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Coffee	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Coffee	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Coffee	...	Boiling	...	Resistant	...	253
317L	S31703	...	Coffee	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Coffee	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Coffee	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Coffee	...	Boiling	...	Resistant	...	253
321	S32100	...	Coffee	...	20 (68)	...	Resistant	...	253
321	S32100	...	Coffee	...	Boiling	...	Resistant	...	253
329	S32900	...	Coffee	...	20 (68)	...	Resistant	...	253
329	S32900	...	Coffee	...	Boiling	...	Resistant	...	253
347	S34700	...	Coffee	...	20 (68)	...	Resistant	...	253
347	S34700	...	Coffee	...	Boiling	...	Resistant	...	253
F51	S31803	...	Coffee	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Coffee	...	Boiling	...	Resistant	...	253
301	S30100	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
302	S30200	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
303	S30300	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
303	S30300	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
304	S30400	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
304L	S30403	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
304LN	S30453	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
316	S31600	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
316F	S31620	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
316LN	S31653	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
316Ti	S31635	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
317L	S31703	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
317LN	S31725	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
321	S32100	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
329	S32900	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
347	S34700	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
430	S43000	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
434	S43400	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
F51	S31803	...	Fresh milk	...	Up to 70° (158°)	...	Resistant	...	253
301	S30100	...	Liqueurs	...	...	...	Resistant	...	253
302	S30200	...	Liqueurs	...	...	...	Resistant	...	253
303	S30300	...	Liqueurs	...	...	...	Resistant	...	253
303	S30300	...	Liqueurs	...	...	...	Resistant	...	253
304	S30400	...	Liqueurs	...	...	...	Resistant	...	253
304L	S30403	...	Liqueurs	...	...	...	Resistant	...	253
304LN	S30453	...	Liqueurs	...	...	...	Resistant	...	253
316	S31600	...	Liqueurs	...	...	...	Resistant	...	253
316F	S31620	...	Liqueurs	...	...	...	Resistant	...	253
316L	S31603	...	Liqueurs	...	...	...	Resistant	...	253
316LN	S31653	...	Liqueurs	...	...	...	Resistant	...	253
316Ti	S31635	...	Liqueurs	...	...	...	Resistant	...	253
317L	S31703	...	Liqueurs	...	...	...	Resistant	...	253
317LN	S31725	...	Liqueurs	...	...	...	Resistant	...	253
321	S32100	...	Liqueurs	...	...	...	Resistant	...	253
329	S32900	...	Liqueurs	...	...	...	Resistant	...	253
347	S34700	...	Liqueurs	...	...	...	Resistant	...	253
403	S40300	...	Liqueurs	...	...	...	Resistant	...	253
405	S40500	...	Liqueurs	...	...	...	Resistant	...	253
409	S40900	...	Liqueurs	...	...	...	Resistant	...	253
410	S41000	...	Liqueurs	...	...	...	Resistant	...	253
416	S41600	...	Liqueurs	...	...	...	Resistant	...	253
420	S42000	...	Liqueurs	...	...	...	Resistant	...	253
430	S43000	...	Liqueurs	...	...	...	Resistant	...	253
434	S43400	...	Liqueurs	...	...	...	Resistant	...	253
F51	S31803	...	Liqueurs	...	...	...	Resistant	...	253
301	S30100	...	Meat	...	...	...	Resistant	...	253
302	S30200	...	Meat	...	...	...	Resistant	...	253
303	S30300	...	Meat	...	...	...	Resistant	...	253
303	S30300	...	Meat	...	...	...	Resistant	...	253
304	S30400	...	Meat	...	...	...	Resistant	...	253
304L	S30403	...	Meat	...	...	...	Resistant	...	253
304LN	S30453	...	Meat	...	...	...	Resistant	...	253
316	S31600	...	Meat	...	...	...	Resistant	...	253
316F	S31620	...	Meat	...	...	...	Resistant	...	253
316L	S31603	...	Meat	...	...	...	Resistant	...	253
316LN	S31653	...	Meat	...	...	...	Resistant	...	253
316Ti	S31635	...	Meat	...	...	...	Resistant	...	253
317L	S31703	...	Meat	...	...	...	Resistant	...	253
317LN	S31725	...	Meat	...	...	...	Resistant	...	253
321	S32100	...	Meat	...	...	...	Resistant	...	253
329	S32900	...	Meat	...	...	...	Resistant	...	253
347	S34700	...	Meat	...	...	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	Meat	...	...	...	Resistant	...	253
434	S43400	...	Meat	...	...	...	Resistant	...	253
F51	S31803	...	Meat	...	...	...	Resistant	...	253
301	S30100	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
403	S40300	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
405	S40500	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
409	S40900	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
410	S41000	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
416	S41600	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
420	S42000	...	Mustard	...	20 (68)	...	Questionable	Pitting	253
430	S43000	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Mustard	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	Pickling liquid	...	...	...	Resistant	...	253
301	S30100	...	Pickling liquid	...	...	...	Resistant	...	253
301	S30100	...	Pickling liquid	...	...	...	Resistant	...	253
302	S30200	...	Pickling liquid	...	...	...	Resistant	...	253
302	S30200	...	Pickling liquid	...	...	...	Resistant	...	253
302	S30200	...	Pickling liquid	...	...	...	Resistant	...	253
303	S30300	...	Pickling liquid	...	...	...	Resistant	...	253
303	S30300	...	Pickling liquid	...	...	...	Resistant	...	253
303	S30300	...	Pickling liquid	...	...	...	Poor	...	253
303	S30300	...	Pickling liquid	...	...	...	Resistant	...	253
303	S30300	...	Pickling liquid	...	...	...	Resistant	...	253
303	S30300	...	Pickling liquid	...	...	...	Resistant	...	253
304	S30400	...	Pickling liquid	...	...	...	Resistant	...	253
304	S30400	...	Pickling liquid	...	...	...	Resistant	...	253
304	S30400	...	Pickling liquid	...	...	...	Resistant	...	253
304L	S30403	...	Pickling liquid	...	...	...	Resistant	...	253
304L	S30403	...	Pickling liquid	...	...	...	Resistant	...	253
304L	S30403	...	Pickling liquid	...	...	...	Resistant	...	253
304LN	S30453	...	Pickling liquid	...	...	...	Resistant	...	253
304LN	S30453	...	Pickling liquid	...	...	...	Resistant	...	253
304LN	S30453	...	Pickling liquid	...	...	...	Resistant	...	253
316	S31600	...	Pickling liquid	...	...	...	Resistant	...	253
316	S31600	...	Pickling liquid	...	...	...	Resistant	...	253
316	S31600	...	Pickling liquid	...	...	...	Resistant	...	253
316F	S31620	...	Pickling liquid	...	...	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	Pickling liquid	...	...	...	Resistant	...	253
316F	S31620	...	Pickling liquid	...	...	...	Resistant	...	253
316L	S31603	...	Pickling liquid	...	...	...	Resistant	...	253
316L	S31603	...	Pickling liquid	...	...	...	Resistant	...	253
316L	S31603	...	Pickling liquid	...	...	...	Resistant	...	253
316LN	S31653	...	Pickling liquid	...	...	...	Resistant	...	253
316LN	S31653	...	Pickling liquid	...	...	...	Resistant	...	253
316LN	S31653	...	Pickling liquid	...	...	...	Resistant	...	253
316Ti	S31635	...	Pickling liquid	...	...	...	Resistant	...	253
316Ti	S31635	...	Pickling liquid	...	...	...	Resistant	...	253
316Ti	S31635	...	Pickling liquid	...	...	...	Resistant	...	253
317L	S31703	...	Pickling liquid	...	...	...	Resistant	...	253
317L	S31703	...	Pickling liquid	...	...	...	Resistant	...	253
317L	S31703	...	Pickling liquid	...	...	...	Resistant	...	253
317LN	S31725	...	Pickling liquid	...	...	...	Resistant	...	253
317LN	S31725	...	Pickling liquid	...	...	...	Resistant	...	253
317LN	S31725	...	Pickling liquid	...	...	...	Resistant	...	253
321	S32100	...	Pickling liquid	...	...	...	Resistant	...	253
321	S32100	...	Pickling liquid	...	...	...	Resistant	...	253
321	S32100	...	Pickling liquid	...	...	...	Resistant	...	253
329	S32900	...	Pickling liquid	...	...	...	Resistant	...	253
329	S32900	...	Pickling liquid	...	...	...	Resistant	...	253
329	S32900	...	Pickling liquid	...	...	...	Resistant	...	253
347	S34700	...	Pickling liquid	...	...	...	Resistant	...	253
347	S34700	...	Pickling liquid	...	...	...	Resistant	...	253
347	S34700	...	Pickling liquid	...	...	...	Resistant	...	253
403	S40300	...	Pickling liquid	...	...	...	Poor	...	253
403	S40300	...	Pickling liquid	...	...	...	Good	...	253
405	S40500	...	Pickling liquid	...	...	...	Poor	...	253
405	S40500	...	Pickling liquid	...	...	...	Good	...	253
409	S40900	...	Pickling liquid	...	...	...	Poor	...	253
409	S40900	...	Pickling liquid	...	...	...	Good	...	253
410	S41000	...	Pickling liquid	...	...	...	Poor	...	253
410	S41000	...	Pickling liquid	...	...	...	Good	...	253
416	S41600	...	Pickling liquid	...	...	...	Poor	...	253
416	S41600	...	Pickling liquid	...	...	...	Good	...	253
420	S42000	...	Pickling liquid	...	...	...	Poor	...	253
420	S42000	...	Pickling liquid	...	...	...	Good	...	253
430	S43000	...	Pickling liquid	...	...	...	Resistant	...	253
430	S43000	...	Pickling liquid	...	...	...	Poor	...	253
430	S43000	...	Pickling liquid	...	...	...	Resistant	...	253
434	S43400	...	Pickling liquid	...	...	...	Resistant	...	253
434	S43400	...	Pickling liquid	...	...	...	Poor	...	253
434	S43400	...	Pickling liquid	...	...	...	Resistant	...	253
F51	S31803	...	Pickling liquid	...	...	...	Resistant	...	253
F51	S31803	...	Pickling liquid	...	...	...	Resistant	...	253
F51	S31803	...	Pickling liquid	...	...	...	Resistant	...	253
301	S30100	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
302	S30200	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
303	S30300	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
304	S30400	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
304L	S30403	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
304LN	S30453	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
316	S31600	...	Sauerkraut liquor	...	...	...	Good	Pitting	253

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Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
316L	S31603	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
316LN	S31653	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
316Ti	S31635	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
317L	S31703	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
317LN	S31725	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
321	S32100	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
329	S32900	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
347	S34700	...	Sauerkraut liquor	...	...	...	Questionable	Pitting	253
F51	S31803	...	Sauerkraut liquor	...	...	...	Good	Pitting	253
301	S30100	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
302	S30200	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
303	S30300	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
303	S30300	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
304	S30400	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
316	S31600	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
321	S32100	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
329	S32900	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
347	S34700	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
403	S40300	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
405	S40500	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
409	S40900	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
410	S41000	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
416	S41600	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
420	S42000	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
430	S43000	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
434	S43400	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Schweinfurt green	...	20 (68)	...	Resistant	...	253
301	S30100	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
302	S30200	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
303	S30300	...	Sour milk	...	Up to 70° (158°)	...	Good	...	253
303	S30300	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
304	S30400	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
304L	S30403	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
304LN	S30453	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
316	S31600	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
316F	S31620	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
316L	S31603	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
316LN	S31653	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
316Ti	S31635	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
317L	S31703	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
317LN	S31725	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
321	S32100	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
329	S32900	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
347	S34700	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
430	S43000	...	Sour milk	...	Up to 70° (158°)	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
F51	S31803	...	Sour milk	...	Up to 70° (158°)	...	Resistant	...	253
301	S30100	...	Sugar solution	...	20 (68)	...	Resistant	...	253
301	S30100	...	Sugar solution	...	Boiling	...	Resistant	...	253
302	S30200	...	Sugar solution	...	20 (68)	...	Resistant	...	253
302	S30200	...	Sugar solution	...	Boiling	...	Resistant	...	253
303	S30300	...	Sugar solution	...	20 (68)	...	Resistant	...	253
303	S30300	...	Sugar solution	...	20 (68)	...	Resistant	...	253
303	S30300	...	Sugar solution	...	Boiling	...	Resistant	...	253
303	S30300	...	Sugar solution	...	Boiling	...	Resistant	...	253
304	S30400	...	Sugar solution	...	20 (68)	...	Resistant	...	253
304	S30400	...	Sugar solution	...	Boiling	...	Resistant	...	253
304L	S30403	...	Sugar solution	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Sugar solution	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Sugar solution	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Sugar solution	...	Boiling	...	Resistant	...	253
316	S31600	...	Sugar solution	...	20 (68)	...	Resistant	...	253
316	S31600	...	Sugar solution	...	Boiling	...	Resistant	...	253
316F	S31620	...	Sugar solution	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Sugar solution	...	Boiling	...	Resistant	...	253
316L	S31603	...	Sugar solution	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Sugar solution	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Sugar solution	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Sugar solution	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Sugar solution	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Sugar solution	...	Boiling	...	Resistant	...	253
317L	S31703	...	Sugar solution	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Sugar solution	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Sugar solution	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Sugar solution	...	Boiling	...	Resistant	...	253
321	S32100	...	Sugar solution	...	20 (68)	...	Resistant	...	253
321	S32100	...	Sugar solution	...	Boiling	...	Resistant	...	253
329	S32900	...	Sugar solution	...	20 (68)	...	Resistant	...	253
329	S32900	...	Sugar solution	...	Boiling	...	Resistant	...	253
347	S34700	...	Sugar solution	...	20 (68)	...	Resistant	...	253
347	S34700	...	Sugar solution	...	Boiling	...	Resistant	...	253
403	S40300	...	Sugar solution	...	20 (68)	...	Resistant	...	253
403	S40300	...	Sugar solution	...	Boiling	...	Resistant	...	253
405	S40500	...	Sugar solution	...	20 (68)	...	Resistant	...	253
405	S40500	...	Sugar solution	...	Boiling	...	Resistant	...	253
409	S40900	...	Sugar solution	...	20 (68)	...	Resistant	...	253
409	S40900	...	Sugar solution	...	Boiling	...	Resistant	...	253
410	S41000	...	Sugar solution	...	20 (68)	...	Resistant	...	253
410	S41000	...	Sugar solution	...	Boiling	...	Resistant	...	253
416	S41600	...	Sugar solution	...	20 (68)	...	Resistant	...	253
416	S41600	...	Sugar solution	...	Boiling	...	Resistant	...	253
420	S42000	...	Sugar solution	...	20 (68)	...	Resistant	...	253
420	S42000	...	Sugar solution	...	Boiling	...	Resistant	...	253
430	S43000	...	Sugar solution	...	20 (68)	...	Resistant	...	253
430	S43000	...	Sugar solution	...	Boiling	...	Resistant	...	253
434	S43400	...	Sugar solution	...	20 (68)	...	Resistant	...	253
434	S43400	...	Sugar solution	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Food Products (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
F51	S31803	...	Sugar solution	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Sugar solution	...	Boiling	...	Resistant	...	253
301	S30100	...	Vinegar	...	20 (68)	...	Resistant	...	253
301	S30100	...	Vinegar	...	Boiling	...	Resistant	...	253
302	S30200	...	Vinegar	...	20 (68)	...	Resistant	...	253
302	S30200	...	Vinegar	...	Boiling	...	Resistant	...	253
303	S30300	...	Vinegar	...	20 (68)	...	Resistant	...	253
303	S30300	...	Vinegar	...	20 (68)	...	Resistant	...	253
303	S30300	...	Vinegar	...	Boiling	...	Good	...	253
303	S30300	...	Vinegar	...	Boiling	...	Resistant	...	253
304	S30400	...	Vinegar	...	20 (68)	...	Resistant	...	253
304	S30400	...	Vinegar	...	Boiling	...	Resistant	...	253
304L	S30403	...	Vinegar	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Vinegar	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Vinegar	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Vinegar	...	Boiling	...	Resistant	...	253
316	S31600	...	Vinegar	...	20 (68)	...	Resistant	...	253
316	S31600	...	Vinegar	...	Boiling	...	Resistant	...	253
316F	S31620	...	Vinegar	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Vinegar	...	Boiling	...	Resistant	...	253
316L	S31603	...	Vinegar	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Vinegar	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Vinegar	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Vinegar	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Vinegar	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Vinegar	...	Boiling	...	Resistant	...	253
317L	S31703	...	Vinegar	...	20 (68)	...	.Resistant	...	253
317L	S31703	...	Vinegar	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Vinegar	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Vinegar	...	Boiling	...	Resistant	...	253
321	S32100	...	Vinegar	...	20 (68)	...	Resistant	...	253
321	S32100	...	Vinegar	...	Boiling	...	Resistant	...	253
329	S32900	...	Vinegar	...	20 (68)	...	Resistant	...	253
329	S32900	...	Vinegar	...	Boiling	...	Resistant	...	253
347	S34700	...	Vinegar	...	20 (68)	...	Resistant	...	253
347	S34700	...	Vinegar	...	Boiling	...	Resistant	...	253
403	S40300	...	Vinegar	...	20 (68)	...	Resistant	...	253
403	S40300	...	Vinegar	...	Boiling	...	Questionable	...	253
405	S40500	...	Vinegar	...	20 (68)	...	Resistant	...	253
405	S40500	...	Vinegar	...	Boiling	...	Questionable	...	253
409	S40900	...	Vinegar	...	20 (68)	...	Resistant	...	253
409	S40900	...	Vinegar	...	Boiling	...	Questionable	...	253
410	S41000	...	Vinegar	...	20 (68)	...	Resistant	...	253
410	S41000	...	Vinegar	...	Boiling	...	Questionable	...	253
416	S41600	...	Vinegar	...	20 (68)	...	Resistant	...	253
416	S41600	...	Vinegar	...	Boiling	...	Questionable	...	253
420	S42000	...	Vinegar	...	20 (68)	...	Resistant	...	253
420	S42000	...	Vinegar	...	Boiling	...	Questionable	...	253
430	S43000	...	Vinegar	...	20 (68)	...	Resistant	...	253
430	S43000	...	Vinegar	...	Boiling	...	Good	...	253
434	S43400	...	Vinegar	...	20 (68)	...	Resistant	...	253
434	S43400	...	Vinegar	...	Boiling	...	Resistant	...	253
F51	S31803	...	Vinegar	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Vinegar	...	Boiling	...	Resistant	...	253

Formaldehyde

Formaldehyde, HCHO, also known as methanol, formol, and methylene oxide, is a colorless gas at room temperature. In solution with water, it is a colorless poisonous liquid with a pungent odor. Formaldehyde is used in the manufacture of plastics and resins by reaction with phenols, urea, and melamine. It is used as a preservative, a disinfectant, and as a chemical intermediate.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Formaldehyde has been distilled, stored, and shipped in aluminum alloy equipment. Valves of aluminum alloy 356.0 are used to handle formaldehyde.

Corrosion Behavior of Various Metals and Alloys in Formaldehyde

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20-100 (68-212)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	20-100	24-52 (75-125)	...	0.5 (20) max	...	95
Magnesium	...	...	...	All	...	...	Resistant	...	119
Platinum	P04995	...	...	All	500 (930)	...	0.05 (2) max	...	6
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	10
Tin	...	...	...	40	20 (68)	...	Resistant	...	94
Tin	...	...	...	40	60 (140)	...	Resistant	...	94
Tin	...	...	...	40	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Niobium	R04210	...	...	37	Boiling	...	0.0025 (0.1)	...	2
Titanium	...	...	...	37	Boiling	...	0.13 (5) max	...	20

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formaldehyde (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	...	37	Boiling	...	Resistant	...	90
Zr702	R60702	...	...	6-37	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	0-70	Room to 100 (room to 212)	...	0.05 (2) max	...	15
Zr705	R60705	...	...	6-37	Boiling	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	40	20 (68)	...	Resistant	...	253
301	S30100	...	...	40	Boiling	...	Resistant	...	253
302	S30200	...	...	40	20 (68)	...	Resistant	...	253
302	S30200	...	...	40	Boiling	...	Resistant	...	253
303	S30300	...	...	40	20 (68)	...	Resistant	...	253
303	S30300	...	...	40	20 (68)	...	Resistant	...	253
303	S30300	...	...	40	Boiling	...	Resistant	...	253
303	S30300	...	...	40	Boiling	...	Resistant	...	253
304	S30400	...	...	40	20 (68)	...	Resistant	...	253
304	S30400	...	...	40	21 (70)	...	Resistant	...	121
304	S30400	...	...	40	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Fractionating tower	10	104 (220)	87 d	0.01 (0.4)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Nozzle on side of Paraform evaporator	84	87-93 (190-200)	35 d	0.003 (0.1)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation	30-70	54-60 (130-140)	99 d	0.003 (0.1) max	...	89
304	S30400	...	Rayon processing; no aeration; slight to moderate agitation	5	98 (210)	560 d	0.03 (1)	...	89
304L	S30403	...	...	40	20 (68)	...	Resistant	...	253
304L	S30403	...	...	40	Boiling	...	Resistant	...	253
304LN	S30453	...	...	40	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	40	Boiling	...	Resistant	...	253
316	S31600	...	...	40	20 (68)	...	Resistant	...	253
316	S31600	...	...	40	21 (70)	...	Resistant	...	121
316	S31600	...	...	40	Boiling	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Fractionating tower	10	104 (220)	87 d	0.015 (0.6)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation	20	135 (275)	71 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Nozzle on side of Paraform evaporator	84	87-93 (190-200)	35 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation	30-70	54-60 (130-140)	99 d	Resistant	...	89
316	S31600	...	Rayon processing; no aeration; slight to moderate agitation	5	98 (210)	560 d	0.003 (0.1)	...	89
316F	S31620	...	...	40	20 (68)	...	Resistant	...	253
316F	S31620	...	...	40	Boiling	...	Resistant	...	253
316L	S31603	...	...	40	20 (68)	...	Resistant	...	253
316L	S31603	...	...	40	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formaldehyde (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	40	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	40	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	40	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	40	Boiling	...	Resistant	...	253
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Fractionating tower	10	104 (220)	87 d	0.003 (0.1) max	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation	20	135 (275)	71 d	0.003 (0.1)	...	89
317	S31700	...	Rayon processing; no aeration; slight to moderate agitation	5	98 (210)	560 d	0.003 (0.1) max	...	89
317L	S31703	...	...	40	20 (68)	...	Resistant	...	253
317L	S31703	...	...	40	Boiling	...	Resistant	...	253
317LN	S31725	...	...	40	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	40	Boiling	...	Resistant	...	253
321	S32100	...	...	40	20 (68)	...	Resistant	...	253
321	S32100	...	...	40	Boiling	...	Resistant	...	253
329	S32900	...	...	40	20 (68)	...	Resistant	...	253
329	S32900	...	...	40	Boiling	...	Resistant	...	253
347	S34700	...	...	40	20 (68)	...	Resistant	...	253
347	S34700	...	...	40	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	40	21 (70)	...	Good	...	121
430	S43000	...	...	40	20 (68)	...	Resistant	...	253
430	S43000	...	...	40	21 (70)	...	Good	...	121
430	S43000	...	...	40	Boiling	...	Resistant	...	253
434	S43400	...	...	40	20 (68)	...	Resistant	...	253
434	S43400	...	...	40	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	...	40	20 (68)	...	Resistant	...	253
F51	S31803	...	...	40	Boiling	...	Resistant	...	253

Formic Acid

Formic acid, HCOOH, also known as methanoic acid, is a colorless, pungent, toxic, corrosive liquid that melts at 8.4 °C (47 °F) and is soluble in water, ether, and alcohol. It is the most highly ionized of the common organic acids and therefore the most corrosive. It reacts readily with many oxidizing and reducing compounds and is somewhat unstable as the concentration approaches 100%, decomposing to carbon monoxide and water.

Formic acid is used as a chemical intermediate and solvent, in dyeing and electroplating processes, and in fumigants. In a reaction with glycerol at 220 °C (430 °F), it is a source of allyl alcohol. Formic acid has also been employed in brewing (to assist fermentation), as a food preservative, and in the preparation of metallic formates and esters.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. High-chromium cast irons, although they exhibit adequate resistance to acetic acid, are more severely corroded by formic acid. High-silicon cast irons exhibit excellent resistance to most organic acids, including formic, in all temperature and concentration ranges.

Alloy Steels. Although they can be used for ambient-temperature storage of some high molecular weight organic acids, alloy steels are attacked rapidly by formic acid.

Stainless Steels. The 400 series stainless steels are usually not resistant to formic acid, except for very dilute, cool solutions. They are seldom used in formic acid service. Type 304 stainless steel has excellent resistance to formic acid at all concentrations at ambient temperatures, and it is the preferred material of construction for storage of the acid. However, type 304 stainless steel is resistant to only 1 to 2% formic acid at the atmospheric boiling temperature, and corrosion tests are advisable whenever type 304 stainless steel is considered for handling formic acid at elevated temperatures.

Type 316 stainless steel shows excellent resistance to formic acid in all concentrations at ambient temperatures and is resistant to at least 5% formic acid at the atmospheric boiling temperature. However, type 316 stainless steel can be seriously attacked by intermediate strengths of formic acid at higher temperatures, and corrosion tests are advisable.

The 20-type alloys, such as 20Cb-3, are more resistant to formic acid than type 316 stainless steel, and their use should be considered in higher concentrations at higher temperatures. Other alloys with chromium and nickel contents higher than those of type 316 stainless steel also show superior resistance to mixtures of formic acid and CH_3COOH and would be expected to perform better in formic acid. Duplex alloys are also reported to be superior to type 316 stainless steel. Weld overlays of 20-type alloys have also been used to alleviate the crevice corrosion of type 316 stainless steel—for example, under gaskets.

A low-carbon niobium-bearing variant of type 446 stainless steel—alloy S44627—appears to have exceptional corrosion resistance to formic acid in preliminary laboratory studies and plant usage. This alloy should be considered for handling formic acid.

Aluminum. Aluminum shows fair resistance to formic acid at any concentration at ambient temperatures as long as there is no contamination of the acid. However, contamination with a wide variety of materials—for example, heavy metal salts—can cause severe corrosion of aluminum. Aluminum has been used to ship concentrated formic acid of about 95 to 99% concentration.

Copper. Copper and its alloys, except yellow brasses which dezincify, respond in approximately the same manner as aluminum to exposure to formic acid. Aluminum bronze is reported to be a superior copper alloy for handling formic acid. The resistance of copper and its alloys to formic acid depends on the presence or absence of oxygen or other oxidizing agents. If free air or other oxidants are present, high corrosion rates will be encountered; if the acid is free of air and other oxidants, copper will provide usable resistance to formic acid at all concentrations to the atmospheric boiling point and even at higher temperatures. Copper and its alloys are probably the most widely used materials for handling formic acid.

Lead. Formic acid in most concentrations corrodes lead at rates that are high enough to preclude the use of lead in these acids.

Nickel. Several of the high-nickel alloys, such as Hastelloy B, Hastelloy C-276, and Hastelloy C-4, have shown outstanding resistance to formic acid in process equipment and are reported to exhibit very good resistance even at temperatures above the atmospheric boiling point.

Niobium. Niobium is resistant to formic acid.

Silver. Silver is resistant to formic acid.

Tantalum. Tantalum is resistant to formic acid.

Titanium. Titanium has shown outstanding resistance to formic acid in laboratory tests and in field usage. However, titanium can be attacked at truly catastrophic rates by anhydrous formic acid. Additional work is needed to determine the precise conditions under which titanium is attacked in formic acid, and until these parameters have been established, titanium should be tested very carefully before use in formic acid approaching 100% concentration at elevated temperatures.

Corrosion Behavior of Various Metals and Alloys in Formic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Questionable	...	92
Aluminum-manganese alloys	...	...	Solution	...	...	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	1.0	Boiling	96 h	0.02 (0.9)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	10.0	Boiling	96 h	0.02 (0.7)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	20.0	Boiling	96 h	0.40 (15.7)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	40.0	Boiling	96 h	0.34 (13.3)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	5.0	Boiling	96 h	0.02 (0.9)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	50.0	Boiling	96 h	0.54 (21.1)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	60.0	Boiling	96 h	0.03 (1.3)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	70.0	Boiling	96 h	0.76 (30.0)	...	102
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	80.0	Boiling	96 h	0.13 (5.0)	...	102

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	Lab tests in deaerated acid	90.0	Boiling	96 h	0.19 (7.6)	...	102
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	1.0	Boiling	96 h	0.02 (0.8)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	5.0	Boiling	96 h	0.02 (0.7)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	10.0	Boiling	96 h	0.02 (0.6)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	20.0	Boiling	96 h	0.20 (7.8)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	50.0	Boiling	96 h	0.26 (10.2)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	60.0	Boiling	96 h	0.05 (2.0)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	70.0	Boiling	96 h	0.76 (30.0)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	80.0	Boiling	96 h	0.20 (7.8)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	90.0	Boiling	96 h	0.22 (8.7)	...	102
Oxygen free extra low phosphorus copper	C10300	...	Lab tests in deaerated acid	40.0	Boiling	96 h	0.14 (5.5)	...	102
Phosphor bronze, 5%	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8%	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Lead	L50045	...	...	10-100	24-100 (75-212)	...	1.25 (50) min	...	95
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Allcorr	N06110	Butt welded	...	10	100 (212)	...	0.015 (0.59)	...	220
Allcorr	N06110	Butt welded	...	10	101 (214)	...	0.010 (0.39)	...	220
Allcorr	N06110	Butt welded	Plus 1% HCl, 0.1% HF	10	66 (151)	...	0.64 (25.2)	Weld attack	220
Alloy 200	N02200	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.34 (13.2) max	...	101
Alloy 200	N02200	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.27 (10.5) max	...	101
Alloy 400	N04400	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.028 (1.1) max	...	101
Alloy 400	N04400	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.068 (2.7) max	...	101
Alloy 600	N06600	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.25 (10.0)	...	101

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Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 625	N06625	...	...	40	Boiling	...	.19 (7.4)	...	222
Alloy 625	N06625	...	...	45	Boiling	...	0.20 (9.0)	...	223
Alloy 625	N06625	Butt welded	...	10	100 (212)	...	0.63 (24.8)	...	220
Alloy 625	N06625	Butt welded	...	10	66 (151)	...	0.015 (0.6)	...	220
Alloy 625	N06625	Butt welded	Plus 1% HCl, 0.1% HF	10	101 (214)	...	6.1 (240)	...	220
Alloy 625	N06625	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.238 (9.4) max	...	101
Alloy 625	N06625	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.19 (7.8) max	...	101
Alloy 825	N08825	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.08 (3.1) max	...	101
Alloy 825	N08825	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.2 (7.9)	...	101
Alloy B-2	N10665	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.001 (0.04) max	...	101
Alloy B-2	N10665	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.01 (0.40) max	...	101
Alloy C-22	N06022	Butt welded	...	10	100 (212)	...	0.58 (22.9)	...	220
Alloy C-22	N06022	Butt welded	...	10	66 (151)	...	0.020 (0.8)	...	220
Alloy C-22	N06022	Butt welded	Plus 1% HCl, 0.1% HF	10	101 (214)	...	0.91 (35.9)	Weld attack	220
Alloy C-22	N06022	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.023 (0.9)	...	101
Alloy C-276	N10276	...	...	20	Boiling	...	0.12 (4.8)	...	222
Alloy C-276	N10276	Butt welded	...	10	100 (212)	...	0.46 (18)	...	220
Alloy C-276	N10276	Butt welded	...	10	66 (151)	...	0.18 (7.1)	...	220
Alloy C-276	N10276	Butt welded	Plus 1% HCl, 0.1% HF	10	101 (214)	...	0.79 (31.1)	Weld attack	220
Alloy C-276	N10276	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.048 (1.9) max	...	101
Alloy C-276	N10276	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.074 (2.9) max	...	101
Alloy C-4	N06455	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.076 (3.0) max	...	101
Alloy C-4	N06455	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.076 (3.0) max	...	101
Alloy G	N06007	...	...	88	Boiling	...	0.13 (5)	...	225
Alloy G	N06007	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.12 (4.6) max	...	101
Alloy G	N06007	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.0132 (5.2) max	...	101
Alloy G-2	N06975	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.067 (2.6) max	...	101
Alloy G-3	N06985	...	...	88	Boiling	...	0.13 (5)	...	212
Alloy G-3	N06985	Mill-annealed	Results based on four 24-h test periods	88	Boiling	24 h	0.15 (5.9) max	...	101
Alloy G-3	N06985	Mill-annealed	Results based on four 24-h test periods	40	...	24 h	0.05 (2.1) max	...	101
Alloy G-30	N06030	...	...	88	Boiling	...	0.05 (2)	...	212
Cabot No.625	N06625	...	Average of four 24-h periods	40	Boiling	24 h	0.19 (7.3)	...	67
Cabot No.625	N06625	...	Average of four 24-h periods	88	Boiling	24 h	0.24 (9.3)	...	67
Carpenter Pyromet Alloy 102	...	Annealed	...	5	...	48 h	0.076 (3.04)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	...	5	...	48 h	0.076 (3.04)	...	30
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	10	Boiling	...	0.01 (0.3) max	...	63

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	20	Boiling	...	0.02 (0.6) max	...	63
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	30	Boiling	...	0.02 (0.7) max	...	63
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	40	Boiling	...	0.02 (0.7) max	...	63
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	60	Boiling	...	0.02 (0.5) max	...	63
Hastelloy B-2	N10665	Heat treated at 1066°C (1950°F), water quenched	...	89	Boiling	...	0.02 (0.5) max	...	63
Hastelloy C-4	N06455	Aged at 899°C (1650°F)	...	20	Boiling	100 h	0.09 (3.5)	...	68
Hastelloy C-4	N06455	As-welded. Gas tungsten arc welded	in lab	20	Boiling	...	0.09 (3.5)	...	68
Hastelloy C-4	N06455	Unwelded. Heat treated at 1066°C (1950°F), water quenched	...	20	Boiling	...	0.07 (2.9)	...	68
Hastelloy G-30	N06030	...	...	88	Boiling	...	.025 (1)	...	225
Nickel 200	N02200	...	Liquid in a still	90	100 (212)	...	0.45 (18)	...	44
Nickel 200	N02200	...	Liquid in storage tank	90	Room	...	0.1 (4)	...	44
Nickel 200	N02200	...	Vapor in a still	90	100 (212)	...	0.175 (7)	...	44
Nickel 200	N02200	...	Vapor in storage tank	90	Room	...	0.175 (7)	...	44
Refractory metals and alloys									
44Co-31Cr-13W	...	Cast specimen	Average of five 24-h periods	89	65 (150)	...	0.002 (0.1)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled. Cast specimen	Average of five 24-h periods	89	65 (150)	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	Cast specimen	Average of five 24-h periods	89	65 (150)	...	0.002 (0.1)	...	53
53Co-30Cr-4.5W	...	Cast specimen	Average of five 24-h periods	89	65 (150)	...	0.002 (0.1)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled Cast specimen	Average of five 24-h periods	89	65 (150)	...	Resistant	...	53
Haynes alloy 6B	...	...	...	60	Boiling	...	1.22 (48)	...	23
Haynes No. 25	R30605	...	...	60	Boiling	...	0.61 (24)	...	23
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	Room	24 h	0.01 (0.1) max	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	Room	24 h	...	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	Room	24 h	0.01 (0.1) max	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	Room	24 h	0.01 (0.1) max	...	68

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	Room	24 h	0.01 (0.1) max	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	66 (150)	24 h	0.01 (0.1) max	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	66 (150)	24 h	...	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	66 (150)	24 h	0.01 (0.1) max	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	Boiling	24 h	0.20 (8.0)	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	Boiling	24 h	0.25 (10)	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	Boiling	24 h	...	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	Boiling	24 h	0.38 (15)	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	Boiling	24 h	0.51 (20)	...	68
Haynes No. 25	R30605	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	Boiling	24 h	0.15 (6.0)	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	Room	24 h	Resistant	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	Room	24 h	0.01 (0.1) max	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	Room	24 h	...	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	Room	24 h	0.01 (0.1) max	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	Room	24 h	0.01 (0.1) max	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	Room	24 h	Resistant	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	66 (150)	24 h	Resistant	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	66 (150)	24 h	0.01 (0.1) max	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	66 (150)	24 h	...	...	68

(Continued)

Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	66 (150)	24 h	Resistant	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	66 (150)	24 h	0.01 (0.1) max	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	66 (150)	24 h	Resistant	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	10	Boiling	24 h	0.10 (4.0)	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	20	Boiling	24 h	0.15 (6.0)	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	30	Boiling	24 h	...	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	40	Boiling	24 h	0.20 (8.0)	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	60	Boiling	24 h	0.15 (6.0)	...	68
Multimet	R30155	Twelve-gage, solution heat treated sheet	Calculated from a minimum of five 24-h periods	89	Boiling	24 h	0.08 (3.0)	...	68
Ti-3-8-6-4-4	R58640	...	...	50	Boiling	...	0.98 (39)	...	33
Ti-3Al-2.5V, grade 9	...	...	...	50	Boiling	...	5.0 (200)	...	91
Ti-550	...	...	...	50	Boiling	...	0.02 (0.8)	...	33
Ti-5Ta	...	...	...	50	Boiling	...	3.2 (126)	...	33
Ti-6-2-4-6	R56260	...	...	50	Boiling	...	0.62 (25)	...	33
Titanium	...	...	...	50	Boiling	...	10.8 (433)	...	91
Titanium	...	...	...	9	50 (122)	...	0.127 (5.08) max	...	90
Titanium	...	...	Aerated	10	100 (212)	...	0.005 (0.2)	...	90
Titanium	...	...	Aerated	25	100 (212)	...	0.001 (0.04)	...	90
Titanium	...	...	Aerated	50	100 (212)	...	0.001 (0.04)	...	90
Titanium	...	...	Aerated	90	100 (212)	...	0.001 (0.04)	...	90
Titanium	...	...	Nonaerated	10	100 (212)	...	Resistant	...	90
Titanium	...	...	Nonaerated	25	100 (212)	...	2.4 (98)	...	90
Titanium	...	...	Nonaerated	50	Boiling	...	3.20 (128)	...	90
Titanium	...	...	Nonaerated	90	100 (212)	...	3.00 (120)	...	90
Titanium, grade 12	R53400	...	...	45	Boiling	...	Resistant	...	33
Titanium, grade 12	R53400	...	...	50	Boiling	...	Resistant	...	33
Titanium, grade 12	R53400	...	...	90	Boiling	...	0.56 (22)	...	33
Titanium, grade 5	R56400	...	...	50	Boiling	...	7.9 (288)	...	33
Titanium, grade 7	R52400	...	...	45	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	...	50	Boiling	...	0.01 (0.4)	...	33
Titanium, grade 7	R52400	...	...	90	Boiling	...	0.06 (2.2)	...	33
Titanium, grade 9	...	...	...	25	88 (190)	...	0.13 (5.2) max	...	33
Titanium, grade 9	...	...	...	50	Boiling	...	5.08 (203)	...	33
Titanium, grade 9	...	...	Nitrogen-sparged	25	35 (95)	...	0.13 (5.2) max	...	33
Titanium, unalloyed	...	...	...	10	100 (212)	...	.005 (0.2) max	...	218
Transage 207	...	...	...	50	Boiling	...	0.90 (36)	...	33
Stainless steels									
18Cr-2Ni-12Mn	S24100	...	Test conducted in three 48-h periods	10	Boiling	48 h	2 (80)	...	47
20Cb-3	N08020	...	...	...	...	...	.18 (7)	...	219
26Cr-1Mo	S44627	...	...	45	Boiling	...	0.08 (3)	...	100
29Cr-4Mo	S44700	...	...	45	Boiling	...	0.05 (2)	...	100

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Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	70 (158)	...	Good	...	253
301	S30100	...	...	10	Boiling	...	Questionable	...	253
301	S30100	...	...	100	20 (68)	...	Resistant	...	253
301	S30100	...	...	100	Boiling	...	Questionable	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	70 (158)	...	Questionable	...	253
301	S30100	...	...	50	Boiling	...	Poor	...	253
301	S30100	...	...	80	20 (68)	...	Resistant	...	253
301	S30100	...	...	80	Boiling	...	Questionable	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	70 (158)	...	Good	...	253
302	S30200	...	...	10	Boiling	...	Questionable	...	253
302	S30200	...	...	100	20 (68)	...	Resistant	...	253
302	S30200	...	...	100	Boiling	...	Questionable	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	70 (158)	...	Questionable	...	253
302	S30200	...	...	50	Boiling	...	Poor	...	253
302	S30200	...	...	80	20 (68)	...	Resistant	...	253
302	S30200	...	...	80	Boiling	...	Questionable	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	70 (158)	...	Good	...	253
303	S30300	...	...	10	70 (158)	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Poor	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	100	20 (68)	...	Good	...	253
303	S30300	...	...	100	20 (68)	...	Resistant	...	253
303	S30300	...	...	100	Boiling	...	Poor	...	253
303	S30300	...	...	100	Boiling	...	Questionable	...	253
303	S30300	...	...	50	20 (68)	...	Questionable	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	70 (158)	...	Questionable	...	253
303	S30300	...	...	50	70 (158)	...	Questionable	...	253
303	S30300	...	...	50	Boiling	...	Poor	...	253
303	S30300	...	...	50	Boiling	...	Poor	...	253
303	S30300	...	...	80	20 (68)	...	Questionable	...	253
303	S30300	...	...	80	20 (68)	...	Resistant	...	253
303	S30300	...	...	80	Boiling	...	Poor	...	253
303	S30300	...	...	80	Boiling	...	Questionable	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	10	70 (158)	...	Good	...	253
304	S30400	...	...	10	Boiling	...	Questionable	...	253
304	S30400	...	...	100	20 (68)	...	Resistant	...	253
304	S30400	...	...	100	Boiling	...	Questionable	...	253
304	S30400	...	...	45	Boiling	...	1.2 (48)	...	100
304	S30400	...	...	45	Boiling	...	17.9 (715)	...	219
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	21 (70)	...	Good	...	121
304	S30400	...	...	50	70 (158)	...	Questionable	...	253
304	S30400	...	...	50	Boiling	...	Poor	...	253
304	S30400	...	...	80	20 (68)	...	Resistant	...	253
304	S30400	...	...	80	Boiling	...	Questionable	...	253
304	S30400	...	No activation	30	Boiling	24 h	2.0 (81)	...	52

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Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	No activation	45	Boiling	24 h	...	...	52
304	S30400	...	Test conducted in three 48-h periods	10	Boiling	48 h	0.6 (24)	...	47
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	70 (158)	...	Good	...	253
304L	S30403	...	...	10	Boiling	...	Questionable	...	253
304L	S30403	...	...	100	20 (68)	...	Resistant	...	253
304L	S30403	...	...	100	Boiling	...	Questionable	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	70 (158)	...	Questionable	...	253
304L	S30403	...	...	50	Boiling	...	Poor	...	253
304L	S30403	...	...	80	20 (68)	...	Resistant	...	253
304L	S30403	...	...	80	Boiling	...	Questionable	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	70 (158)	...	Good	...	253
304LN	S30453	...	...	10	Boiling	...	Questionable	...	253
304LN	S30453	...	...	100	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	100	Boiling	...	Questionable	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	70 (158)	...	Questionable	...	253
304LN	S30453	...	...	50	Boiling	...	Poor	...	253
304LN	S30453	...	...	80	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	80	Boiling	...	Questionable	...	253
316	S31600	...	...	...	...	...	13.0 (520)	...	219
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	10	70 (158)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Good	...	253
316	S31600	...	...	100	20 (68)	...	Resistant	...	253
316	S31600	...	...	100	Boiling	...	Good	...	253
316	S31600	...	...	20	Boiling	...	0.08 (3.1)	...	51
316	S31600	...	...	45	Boiling	...	0.27 (11)	...	100
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	21 (70)	...	Resistant	...	121
316	S31600	...	...	50	70 (158)	...	Good	...	253
316	S31600	...	...	50	Boiling	...	Good	...	253
316	S31600	...	...	80	20 (68)	...	Resistant	...	253
316	S31600	...	...	80	Boiling	...	Good	...	253
316	S31600	...	No activation	30	Boiling	24 h	0.73 (29)	...	52
316	S31600	...	No activation	45	Boiling	24 h	...	...	52
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	70 (158)	...	Good	...	253
316F	S31620	...	...	10	Boiling	...	Questionable	...	253
316F	S31620	...	...	100	20 (68)	...	Resistant	...	253
316F	S31620	...	...	100	Boiling	...	Questionable	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	70 (158)	...	Questionable	...	253
316F	S31620	...	...	50	Boiling	...	Poor	...	253
316F	S31620	...	...	80	20 (68)	...	Resistant	...	253
316F	S31620	...	...	80	Boiling	...	Questionable	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	70 (158)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Good	...	253
316L	S31603	...	...	100	20 (68)	...	Resistant	...	253
316L	S31603	...	...	100	Boiling	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	45	Boiling	...	0.60 (23.4)	...	223
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	70 (158)	...	Good	...	253
316L	S31603	...	...	50	Boiling	...	Good	...	253
316L	S31603	...	...	80	20 (68)	...	Resistant	...	253
316L	S31603	...	...	80	Boiling	...	Good	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	70 (158)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Good	...	253
316LN	S31653	...	...	100	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	100	Boiling	...	Good	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	70 (158)	...	Good	...	253
316LN	S31653	...	...	50	Boiling	...	Good	...	253
316LN	S31653	...	...	80	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	80	Boiling	...	Good	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	70 (158)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Good	...	253
316Ti	S31635	...	...	100	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	100	Boiling	...	Good	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	70 (158)	...	Good	...	253
316Ti	S31635	...	...	50	Boiling	...	Good	...	253
316Ti	S31635	...	...	80	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	80	Boiling	...	Good	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	70 (158)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Good	...	253
317L	S31703	...	...	100	20 (68)	...	Resistant	...	253
317L	S31703	...	...	100	Boiling	...	Good	...	253
317L	S31703	...	...	20	Boiling	...	.21 (8.5)	...	219
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	70 (158)	...	Good	...	253
317L	S31703	...	...	50	Boiling	...	Good	...	253
317L	S31703	...	...	80	20 (68)	...	Resistant	...	253
317L	S31703	...	...	80	Boiling	...	Good	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	70 (158)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Good	...	253
317LN	S31725	...	...	100	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	100	Boiling	...	Good	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	70 (158)	...	Good	...	253
317LN	S31725	...	...	50	Boiling	...	Good	...	253
317LN	S31725	...	...	80	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	80	Boiling	...	Good	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	70 (158)	...	Good	...	253
321	S32100	...	...	10	Boiling	...	Questionable	...	253
321	S32100	...	...	100	20 (68)	...	Resistant	...	253
321	S32100	...	...	100	Boiling	...	Questionable	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	70 (158)	...	Questionable	...	253
321	S32100	...	...	50	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	80	20 (68)	...	Resistant	...	253
321	S32100	...	...	80	Boiling	...	Questionable	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	70 (158)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Good	...	253
329	S32900	...	...	100	20 (68)	...	Resistant	...	253
329	S32900	...	...	100	23	70 d	0.003 (0.1) max	...	238
329	S32900	...	...	100	Boiling	...	Good	...	253
329	S32900	...	...	20	23	70 d	0.003 (0.1) max	...	238
329	S32900	...	...	40	23	70 d	0.003 (0.1) max	...	238
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	70 (158)	...	Good	...	253
329	S32900	...	...	50	Boiling	...	Good	...	253
329	S32900	...	...	60	23	70 d	0.003 (0.1) max	...	238
329	S32900	...	...	80	20 (68)	...	Resistant	...	253
329	S32900	...	...	80	23	70 d	0.003 (0.1) max	...	238
329	S32900	...	...	80	Boiling	...	Good	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	70 (158)	...	Good	...	253
347	S34700	...	...	10	Boiling	...	Questionable	...	253
347	S34700	...	...	100	20 (68)	...	Resistant	...	253
347	S34700	...	...	100	Boiling	...	Questionable	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	70 (158)	...	Questionable	...	253
347	S34700	...	...	50	Boiling	...	Poor	...	253
347	S34700	...	...	80	20 (68)	...	Resistant	...	253
347	S34700	...	...	80	Boiling	...	Questionable	...	253
403	S40300	...	...	10	20 (68)	...	Questionable	...	253
403	S40300	...	...	10	70 (158)	...	Poor	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	...	100	20 (68)	...	Good	...	253
403	S40300	...	...	100	Boiling	...	Poor	...	253
403	S40300	...	...	50	20 (68)	...	Questionable	...	253
403	S40300	...	...	50	70 (158)	...	Poor	...	253
403	S40300	...	...	50	Boiling	...	Poor	...	253
403	S40300	...	...	80	20 (68)	...	Questionable	...	253
403	S40300	...	...	80	Boiling	...	Poor	...	253
405	S40500	...	...	10	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	70 (158)	...	Poor	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	...	100	20 (68)	...	Good	...	253
405	S40500	...	...	100	Boiling	...	Poor	...	253
405	S40500	...	...	50	20 (68)	...	Questionable	...	253
405	S40500	...	...	50	70 (158)	...	Poor	...	253
405	S40500	...	...	50	Boiling	...	Poor	...	253
405	S40500	...	...	80	20 (68)	...	Questionable	...	253
405	S40500	...	...	80	Boiling	...	Poor	...	253
409	S40900	...	...	10	20 (68)	...	Questionable	...	253
409	S40900	...	...	10	70 (158)	...	Poor	...	253
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	...	100	20 (68)	...	Good	...	253
409	S40900	...	...	100	Boiling	...	Poor	...	253
409	S40900	...	...	50	20 (68)	...	Questionable	...	253
409	S40900	...	...	50	70 (158)	...	Poor	...	253
409	S40900	...	...	50	Boiling	...	Poor	...	253

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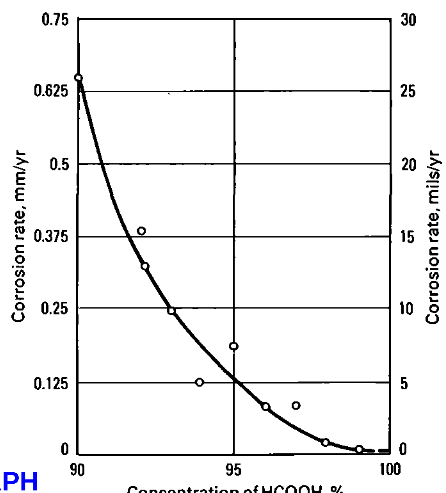
Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	80	20 (68)	...	Questionable	...	253
409	S40900	...	...	80	Boiling	...	Poor	...	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	10	20 (68)	...	Questionable	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	10	70 (158)	...	Poor	...	253
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	...	100	20 (68)	...	Good	...	253
410	S41000	...	...	100	Boiling	...	Poor	...	253
410	S41000	...	...	50	20 (68)	...	Questionable	...	253
410	S41000	...	...	50	21 (70)	...	Poor	...	121
410	S41000	...	...	50	70 (158)	...	Poor	...	253
410	S41000	...	...	50	Boiling	...	Poor	...	253
410	S41000	...	...	80	20 (68)	...	Questionable	...	253
410	S41000	...	...	80	Boiling	...	Poor	...	253
416	S41600	...	...	10	20 (68)	...	Questionable	...	253
416	S41600	...	...	10	70 (158)	...	Poor	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	...	100	20 (68)	...	Good	...	253
416	S41600	...	...	100	Boiling	...	Poor	...	253
416	S41600	...	...	50	20 (68)	...	Questionable	...	253
416	S41600	...	...	50	70 (158)	...	Poor	...	253
416	S41600	...	...	50	Boiling	...	Poor	...	253
416	S41600	...	...	80	20 (68)	...	Questionable	...	253
416	S41600	...	...	80	Boiling	...	Poor	...	253
420	S42000	...	...	10	20 (68)	...	Questionable	...	253
420	S42000	...	...	10	70 (158)	...	Poor	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	...	100	20 (68)	...	Good	...	253
420	S42000	...	...	100	Boiling	...	Poor	...	253
420	S42000	...	...	50	20 (68)	...	Questionable	...	253
420	S42000	...	...	50	70 (158)	...	Poor	...	253
420	S42000	...	...	50	Boiling	...	Poor	...	253
420	S42000	...	...	80	20 (68)	...	Questionable	...	253
420	S42000	...	...	80	Boiling	...	Poor	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Questionable	...	121
430	S43000	...	...	10	70 (158)	...	Questionable	...	253
430	S43000	...	...	10	Boiling	...	Poor	...	253
430	S43000	...	...	100	20 (68)	...	Good	...	253
430	S43000	...	...	100	Boiling	...	Poor	...	253
430	S43000	...	...	50	20 (68)	...	Questionable	...	253
430	S43000	...	...	50	21 (70)	...	Poor	...	121
430	S43000	...	...	50	70 (158)	...	Questionable	...	253
430	S43000	...	...	50	Boiling	...	Poor	...	253
430	S43000	...	...	80	20 (68)	...	Questionable	...	253
430	S43000	...	...	80	Boiling	...	Poor	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	70 (158)	...	Good	...	253
434	S43400	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	100	20 (68)	...	Resistant	...	253
434	S43400	...	...	100	Boiling	...	Questionable	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	70 (158)	...	Good	...	253
434	S43400	...	...	50	Boiling	...	Poor	...	253

(Continued)

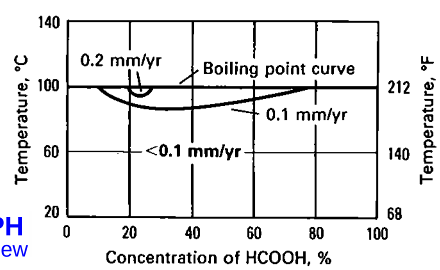
Corrosion Behavior of Various Metals and Alloys in Formic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	80	20 (68)	...	Resistant	...	253
434	S43400	...	...	80	Boiling	...	Questionable	...	253
444	S44400	...	...	45	Boiling	...	5.40 (212)	...	223
444	S44400	...	No activation	30	Boiling	24 h	0.85 (34)	...	52
444	S44400	...	No activation	45	Boiling	24 h	5.3 (212)	...	52
AL 2205	S31803	...	...	...	...	...	.03 (1.3)	...	219
AL 2205	S31803	...	...	...	...	...	.12 (4.9)	...	219
AL 29-4-2	S44800	...	...	45	Boiling	...	0.02 (0.7)	...	223
AL 29-4C	S44735	...	...	45	Boiling	...	0.01 (0.1) max	...	223
E-Brite	S44627	...	...	45	Boiling	...	0.07 (2.6)	...	223
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	70 (158)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Good	...	253
F51	S31803	...	...	100	20 (68)	...	Resistant	...	253
F51	S31803	...	...	100	Boiling	...	Good	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	70 (158)	...	Good	...	253
F51	S31803	...	...	50	Boiling	...	Good	...	253
F51	S31803	...	...	80	20 (68)	...	Resistant	...	253
F51	S31803	...	...	80	Boiling	...	Good	...	253
Ferralium 225	S32550	...	...	...	...	...	.01 (0.4)	...	219
Ferralium	S32550	...	...	20	Boiling	...	0.2 (6.5)	...	51



LIVE GRAPH
Click here to view

Aluminum alloy. Corrosion of aluminum alloy 5086 in formic acid at 45 °C (115 °F). Source: Chemical Processing Industry.



LIVE GRAPH
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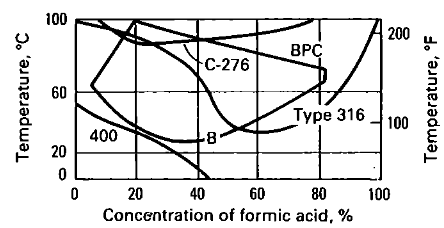
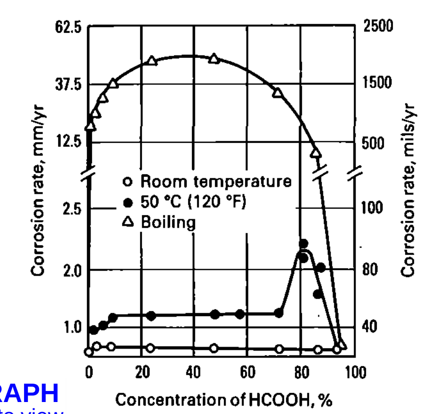
Nickel alloy. Corrosion of Hastelloy C in formic acid. Source: Haynes International.



Nickel alloys. Isocorrosion curves (0.1 mm/yr, or 4 mils/yr) of various nickel-base alloys in formic acid. BPC, boiling point curve. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 649.



LIVE GRAPH
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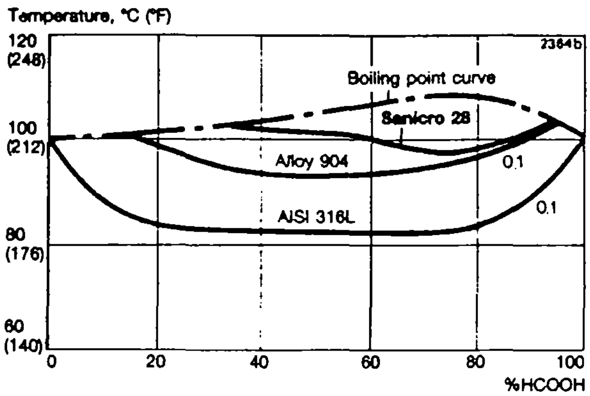
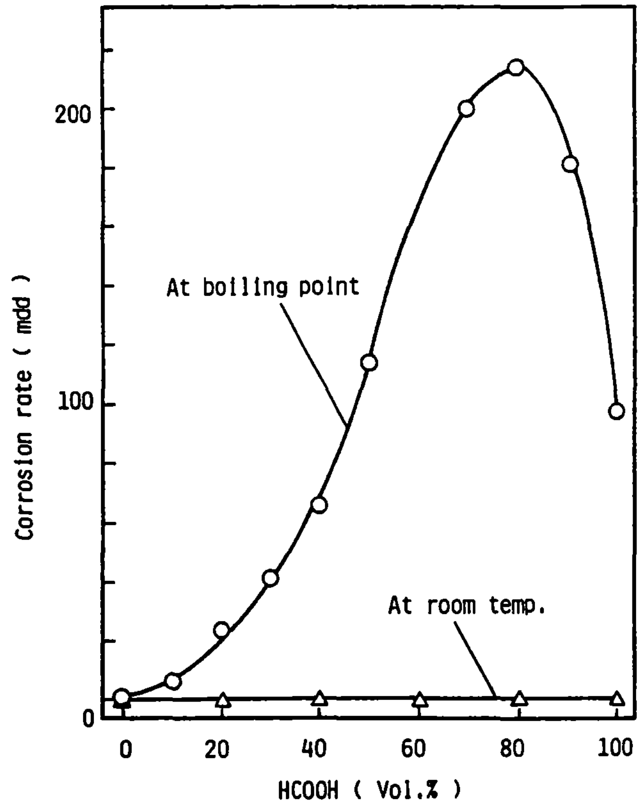
Aluminum alloy. Corrosion of aluminum alloy 1100-H14 in aqueous reagent grade formic acid solutions. Source: Chemical Processing Industry.



Stainless steels. Iso-corrosion diagram for stainless steels in formic acid. The curves represent a corrosion rate of 0.1 mm/y (4 mpy). Ref. 217

LIVE GRAPH
Click here to view



Duplex stainless steel, SUS 329J1. Corrosion rate versus the concentration of HCOOH for SUS 329J1 duplex stainless steel at room temperature and at boiling point. Ref. 238

LIVE GRAPH
Click here to view

Fruit Juices

Many fruit juices can cause corrosion of metals and alloys because of the presence of acids such as citric acid. However, dextrose, proteins and pectin in fruits can also act as natural inhibitors.

Magnesium alloys are generally resistant but corrosion is measurable. Likewise, aluminum alloys 3003, 5052 and 5086 are frequently used for ambient and refrigerated temperature handling of fruit juices, although unfermented grape juice has caused mild attack of 1100, 3003 and 3004 alloys at room temperature. At 100 °C, pineapple juice was corrosive to alloy 3003. Cooking and storage of tomatoes in aluminum containers can cause pitting. In these latter cases of corrosion on aluminum, stainless steel equipment can be effective. Moreover, nickel base alloys can be used under the most aggressive conditions.

Corrosion Behavior of Various Metals and Alloys in Fruit Juices

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Nickel 200	N02200	...	85% grapefruit juice, 15% orange juice, aerated	...	22 (72)	...	0.55 (22)	...	249
Nickel 200	N02200	...	Apple juice, aerated	...	22 (72)	...	0.01 (0.4)	...	249

(Continued)

Corrosion Behavior of Various Metals and Alloys in Fruit Juices (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	Apple juice, unaerated	...	22 (72)	...	0.003 (0.1)	...	249
Nickel 200	N02200	...	Grape juice, aerated	...	22 (72)	...	0.63 (25)	...	249
Nickel 200	N02200	...	Grape juice, unaerated	...	22 (72)	...	0.15 (6)	...	249
Nickel 200	N02200	...	Grape juice, under reflux	...	Boiling	...	0.18 (7)	...	249
Nickel 200	N02200	...	Grapefruit juice, 2.7% citric acid, cold	...	22 (72)	...	0.02 (0.6)	...	249
Nickel 200	N02200	...	Lemon juice, aerated	...	22 (72)	...	0.50 (20)	...	249
Nickel 200	N02200	...	Lemon juice, unaerated	...	22 (72)	...	0.13 (0.5)	...	249
Nickel 200	N02200	...	Lemon juice, under reflux	...	Boiling	...	0.35 (14)	...	249
Nickel 200	N02200	...	Orange juice, under reflux	...	Boiling	...	0.20 (5)	...	249
Nickel 200	N02200	...	Pineapple juice, aerated	...	22 (72)	...	0.45 (18)	...	249
Nickel 200	N02200	...	Pineapple juice, aerated	...	82 (182)	...	0.90 (36)	...	249
Nickel 200	N02200	...	Pineapple juice, aerated	...	74-79 (165-175)	...	0.11 (4.5)	...	249
Nickel 200	N02200	...	Pineapple juice, unaerated	...	22 (72)	...	0.10 (4)	...	249
Nickel 200	N02200	...	Tomato juice, aerated	...	22 (72)	...	0.30 (12)	...	249
Nickel 200	N02200	...	Tomato juice, aerated	...	77 (170)	...	0.10 (44)	...	249
Nickel 200	N02200	...	Tomato juice, aerated	...	91 (195)	...	0.40 (16)	...	249
Nickel 200	N02200	...	Tomato juice, unaerated	...	22 (72)	...	0.20 (8)	...	249
Alloy 400	N04400	...	Grape juice, aerated	...	22 (72)	...	0.12 (4.6)	...	249
Alloy 400	N04400	...	Grape juice, unaerated	...	22 (72)	...	0.05 (2.1)	...	249
Alloy 400	N04400	...	Grape juice, under reflux	...	Boiling	...	0.008 (0.3)	...	249
Alloy 400	N04400	...	Lemon juice, aerated	...	22 (72)	...	0.25 (10)	...	249
Alloy 400	N04400	...	Lemon juice, unaerated	...	22 (72)	...	0.13 (0.5)	...	249
Alloy 400	N04400	...	Lemon juice, under reflux	...	Boiling	...	0.02 (0.7)	...	249
Alloy 400	N04400	...	Orange juice, under reflux	...	Boiling	...	0.03 (1.0)	...	249
Alloy 400	N04400	...	Pineapple juice, aerated	...	22 (72)	...	0.13 (5.1)	...	249
Alloy 400	N04400	...	Pineapple juice, aerated	...	82 (182)	...	0.75 (30)	...	249
Alloy 400	N04400	...	Pineapple juice, aerated	...	74-79 (165-175)	...	0.06 (2.5)	...	249
Alloy 400	N04400	...	Pineapple juice, unaerated	...	22 (72)	...	0.02 (0.7)	...	249
Alloy 400	N04400	...	Tomato juice, unaerated	...	22 (72)	...	.008 (0.03)	...	249
Alloy 400	N04400	...	Tomato juice, aerated	...	22 (72)	...	.08 (3.0)	...	249
Alloy 400	N04400	...	Tomato juice, aerated	...	77 (170)	...	0.18 (7.3)	...	249
Alloy 400	N04400	...	Tomato juice, aerated	...	91 (195)	...	.28 (11)	...	249
Stainless steels									
301	S30100	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
301	S30100	...	Fruit pulp	...	Boiling	...	Resistant	...	253
301	S30100	...	Fruit pulp	...	...	...	Resistant	...	253
301	S30100	...	Lemon juice	...	20 (68)	...	Resistant	...	253
302	S30200	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
302	S30200	...	Fruit pulp	...	Boiling	...	Resistant	...	253
302	S30200	...	Fruit pulp	...	...	...	Resistant	...	253
302	S30200	...	Lemon juice	...	20 (68)	...	Resistant	...	253
303	S30300	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
303	S30300	...	Fruit pulp	...	Boiling	...	Resistant	...	253
303	S30300	...	Fruit pulp	...	...	...	Good	...	253
303	S30300	...	Fruit pulp	...	...	...	Resistant	...	253
303	S30300	...	Lemon juice	...	20 (68)	...	Resistant	...	253
304	S30400	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
304	S30400	...	Fruit pulp	...	Boiling	...	Resistant	...	253
304	S30400	...	Fruit pulp	...	...	...	Resistant	...	253
304	S30400	...	Lemon juice	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Fruit pulp	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Fruit Juices (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	Fruit pulp	...	Boiling	...	Resistant	...	253
304L	S30403	...	Fruit pulp	...	...	...	Resistant	...	253
304L	S30403	...	Lemon juice	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Fruit pulp	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Fruit pulp	...	...	...	Resistant	...	253
304LN	S30453	...	Lemon juice	...	20 (68)	...	Resistant	...	253
316	S31600	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
316	S31600	...	Fruit pulp	...	Boiling	...	Resistant	...	253
316	S31600	...	Fruit pulp	...	...	...	Resistant	...	253
316	S31600	...	Lemon juice	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Fruit pulp	...	Boiling	...	Resistant	...	253
316F	S31620	...	Fruit pulp	...	...	...	Resistant	...	253
316F	S31620	...	Lemon juice	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Fruit pulp	...	Boiling	...	Resistant	...	253
316L	S31603	...	Fruit pulp	...	...	...	Resistant	...	253
316L	S31603	...	Lemon juice	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Fruit pulp	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Fruit pulp	...	...	...	Resistant	...	253
316LN	S31653	...	Lemon juice	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Fruit pulp	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Fruit pulp	...	...	...	Resistant	...	253
316Ti	S31635	...	Lemon juice	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Fruit pulp	...	Boiling	...	Resistant	...	253
317L	S31703	...	Fruit pulp	...	...	...	Resistant	...	253
317L	S31703	...	Lemon juice	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Fruit pulp	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Fruit pulp	...	...	...	Resistant	...	253
317LN	S31725	...	Lemon juice	...	20 (68)	...	Resistant	...	253
321	S32100	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
321	S32100	...	Fruit pulp	...	Boiling	...	Resistant	...	253
321	S32100	...	Fruit pulp	...	...	...	Resistant	...	253
321	S32100	...	Lemon juice	...	20 (68)	...	Resistant	...	253
347	S34700	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
347	S34700	...	Fruit pulp	...	Boiling	...	Resistant	...	253
347	S34700	...	Fruit pulp	...	...	...	Resistant	...	253
347	S34700	...	Lemon juice	...	20 (68)	...	Resistant	...	253
329	S32900	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
329	S32900	...	Fruit pulp	...	Boiling	...	Resistant	...	253
329	S32900	...	Fruit pulp	...	...	...	Resistant	...	253
329	S32900	...	Lemon juice	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Fruit pulp	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Fruit pulp	...	Boiling	...	Resistant	...	253
F51	S31803	...	Fruit pulp	...	...	...	Resistant	...	253
F51	S31803	...	Lemon juice	...	20 (68)	...	Resistant	...	253
430	S43000	...	Fruit pulp	...	...	...	Good	...	253

Gallic Acid

Colorless crystalline needles or prisms obtained from nutgall tannins, gallic acid is soluble in water and alcohol and melts at 235 to 240 °C. Also known as trihydroxybenzoic acid, it is used in photography, tanning, ink manufacture and pharmaceuticals.

Corrosion Behavior of Various Metals and Alloys in Gallic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Gasoline

Known as petrol to the British and denzin to the Germans, is a mixture of C_4 to C_{12} hydrocarbons. Natural gasoline obtained by fractional distillation of petroleum contains mostly saturated hydrocarbons. The ordinary commercial grades of motor gasoline contain paraffins, olefins, naphthenes, and aromatics, all in substantial concentrations. Motor gasolines are made chiefly by cracking processes in which heavier petroleum factions are converted into more volatile fractions by thermal or catalytic decomposition. Where petroleum is scarce, as in Germany, gasoline also has been made commercially by catalytic high-pressure hydrocarbons from carbon monoxide and hydrogen. Some gasolines sold in the USA contain a minor proportion of tetraethyllead, which is added in concentrations not exceeding 3 mil per gallon of motor gasoline to prevent "knock" in engines in which the gasoline is used as fuel. Commercial grades of tetraethyllead or Ethyl fluid typically contain about 63% tetraethyllead and about 35% ethylene dichloride or dibromide which aids in evacuating the products of the lead from engines. In addition, the fluid contains a red or a blue dye. All leaded gasolines are dyed for recognition and should be used only as motor fuel. Other materials occasionally blended in gasoline, particularly in Europe, to decrease knock are benzene and ethanol.

Gasoline is a highly flammable, mobile liquid with characteristic odor. Evaporates quickly and is insoluble in water, freely soluble in alcohol, ether, chloroform, and benzene; and dissolves fats, oils, and natural resins. Used as fuel in internal combustion engines of the spark-ignited reciprocating type.

Corrosion Behavior of Various Metals and Alloys in Gasoline

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253

Gelatin

Gelatin, also known as glutin, is a protein found in many animal tissues including skin, cartilage, horn, and bone. Gelatin is used in leather dressings, in photography, in metallurgy, in the plastics industry, and in pharmaceuticals.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys have excellent resistance to gelatin. In fact, aluminum is approved by the Pure Food and Drug Administration for use in the production of edible gelatin. Finished gelatin solutions are not handled in unprotected aluminum containers because of the corrosive presence of salt. Gelatin is obtained by the digestion of pork skins, calf skins, and animal bones in dilute solutions of phosphoric acid, hydrochloric acid, nitric acid, and sulfuric acid. The pH of the desired gelatin (pH ranges from 3 to 7) determines the concentration of the acid. The reaction occurs at 66 °C (150 °F) in aluminum vats. Aluminum alloy equipment has also been used in evaporators, piping, tubing, tanks, pumps, and conveyors.

Corrosion Behavior of Various Metals and Alloys in Gelatin

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Tin	...	...	...	...	100 (212)	...	Resistant	...	94
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Stainless steels									
304	S30400	...	Food processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus <0.6% hydrochloric acid	...	13 (55)	11 d	0.008 (0.3)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Gelatin (Continued)

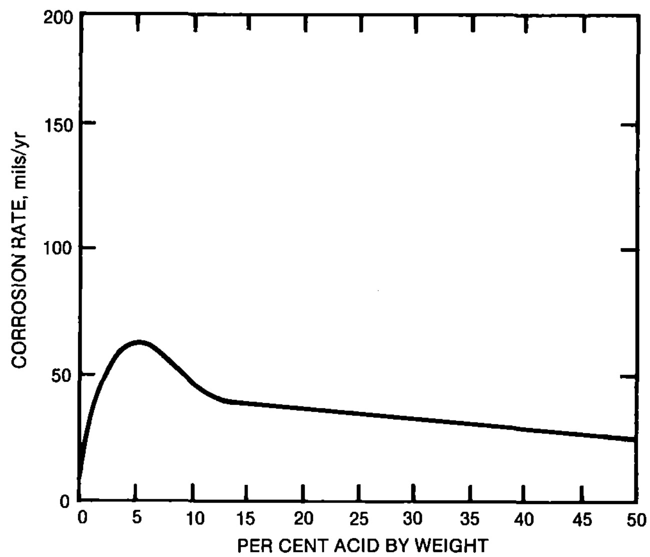
Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Food processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Liquor, acidified with hydrochloric acid to pH 3.8-4.8	...	54-65 (130-150)	55 d	0.003 (0.1)	...	89
304	S30400	...	Food processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Evaporated. Plus 0.75% salts, acidified with hydrochloric acid to pH 3	20-30	43 (110)	100 d	0.010 (0.4)	Crevice attack	89
316	S31600	...	Food processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus <0.6% hydrochloric acid.	...	13 (55)	11 d	0.005 (0.2)	...	89
316	S31600	...	Food processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Liquor, acidified with hydrochloric acid to pH 3.8-4.8	...	54-65 (130-150)	55 d	0.003 (0.1)	...	89
316	S31600	...	Food processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Evaporated. Plus 0.75% salts, acidified with hydrochloric acid to pH 3	20-30	43 (110)	100 d	0.003 (0.1) max	Crevice attack	89
317	S31700	...	Food processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Evaporated. Plus 0.75% salts, acidified with hydrochloric acid to pH 3	20-30	43 (110)	100 d	0.003 (0.1) max	Crevice attack	89

Gluconic Acid

Gluconic acid, $C_5H_6(OH)_5COOH$, also known as dextronic acid, is a white crystalline acid. It is obtained by the oxidation of glucose and is used in cleaning metals.

Corrosion Behavior of Various Metals and Alloys in Gluconic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	4
Refractory metals and alloys									
Titanium	...	...	...	50	Room	...	Resistant	...	90
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation	50	43-66 (110-150)	99 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; field or pilot plant test; pH 2 (evaporator, liquid level)	~50	60-66 (140-150)	99 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation	50	43-66 (110-150)	99 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; pH 2 (evaporator, liquid level)	~50	60-66 (140-150)	99 d	0.003 (0.1) max	...	89



Aluminum. Effect of gluconic acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 33.

LIVE GRAPH
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Glue

A crude, impure, amber-colored form of commercial gelatin of unknown detailed composition produced by hydrolysis of animal collagen; gelatiomizes in aqueous solutions and dried to form a strong, adhesive layer.

Corrosion Behavior of Various Metals and Alloys in Glue

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Glue (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Glycerol

Glycerol, $CH_2OHCHOHCH_2OH$, also known as glycerin and glycyl alcohol, is a colorless nontoxic liquid with a sweet taste. It is the simplest trihydroxy alcohol and a valuable chemical intermediary. It is soluble in water and alcohol, but only partially soluble in ether and ethyl acetate. Glycerol is used in perfume and medicine, as an antifreeze, and in manufacturing soaps and explosives.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. Unalloyed cast irons can be used to handle glycerol, although slight discolorization of the glycerol may result. High-silicon cast irons also exhibit excellent resistance to glycerol.

Aluminum. Aluminum alloy 3003 is resistant to glycerol solutions at all temperatures in laboratory tests. Glycerol has been distilled, condensed, stored and shipped in aluminum alloy equipment. Aluminum alloy 356.0 valves have been used for handling glycerol.

Corrosion Behavior of Various Metals and Alloys in Glycerol

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	7
Lead	L50045	...	...	...	24 (75)	...	0.5 (20) max	...	95
Magnesium	...	...	Chemically pure	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Nickel and alloys									
Alloy 825	N08825	...	Soap processing; field or pilot plant test; no aeration; no agitation. Glycerine saturated with salt (Wooster-Sanger evaporator)	15-80	60-104 (140-220)	91 d	0.003 (0.1) max	Crevice attack	89
Refractory metals and alloys									
Titanium	...	...	...	...	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	Concentrated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Concentrated	Boiling	...	Resistant	...	253
302	S30200	...	...	Concentrated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Glycerol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	Concentrated	Boiling	...	Resistant	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	Boiling	...	Resistant	...	253
303	S30300	...	...	Concentrated	Boiling	...	Resistant	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Concentrated	Boiling	...	Resistant	...	253
304	S30400	...	Soap (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Concentrated glycerine saturated with salt, salt crystals	...	160 (320) max	124 d	0.20 (7.9)	Slight pitting; crevice attack	89
304	S30400	...	Soap processing; field or pilot plant test; no aeration; no agitation. Glycerine saturated with salt (Wooster-Sanger evaporator)	15-80	60-104 (140-220)	91 d	0.008 (0.3)	Severe pitting; crevice attack	89
304L	S30403	...	...	Concentrated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Concentrated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	Boiling	...	Resistant	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	Boiling	...	Resistant	...	253
316	S31600	...	Soap (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Concentrated glycerine saturated with salt, salt crystals	...	160 (320) max	124 d	0.20 (7.8)	Moderate pitting; crevice attack	89
316	S31600	...	Soap processing; field or pilot plant test; no aeration; no agitation. Glycerine saturated with salt (Wooster-Sanger evaporator)	15-80	60-104 (140-220)	91 d	0.003 (0.1)	Slight pitting; crevice attack	89
316F	S31620	...	...	Concentrated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Concentrated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Concentrated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	Boiling	...	Resistant	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Concentrated	Boiling	...	Resistant	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	Boiling	...	Resistant	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Concentrated	Boiling	...	Resistant	...	253
403	S40300	...	...	Concentrated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Concentrated	Boiling	...	Resistant	...	253
405	S40500	...	...	Concentrated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Concentrated	Boiling	...	Resistant	...	253
409	S40900	...	...	Concentrated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Concentrated	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	Concentrated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Concentrated	Boiling	...	Resistant	...	253
416	S41600	...	...	Concentrated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Concentrated	Boiling	...	Resistant	...	253
420	S42000	...	...	Concentrated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Glycerol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	Concentrated	Boiling	...	Resistant	...	253
430	S43000	...	...	Concentrated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Concentrated	Boiling	...	Resistant	...	253
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Concentrated	Boiling	...	Resistant	...	253
Carpenter 20	...	...	Soap processing; field or pilot plant test; no aeration; no agitation. Glycerine saturated with salt (Wooster-Sanger evaporator)	15-80	60-104 (140-220)	91 d	0.003 (0.1) max	Crevice attack	89
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	Boiling	...	Resistant	...	253

Glycolic Acid

Glycolic acid, $CH_2OHCOOH$, also known as hydroxyacetic acid, is composed of colorless deliquescent leaflets that decompose at approximately 78 °C (172 °F). It is soluble in water, alcohol, and ether. Glycolic acid is used in dyeing, tanning, electropolishing, and in foodstuffs. It is produced by oxidizing glycol with dilute nitric acid.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003 and 5154 were reported to be attacked by glycolic acid at 100 °C (212 °F) in laboratory tests. Aluminum alloy containers have been used to ship and store glycolic acid solutions.

Corrosion Behavior of Various Metals and Alloys in Glycolic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Zr702	R60702	...	...	...	40 (104)	...	0.13 (5) max	...	15

Hydrazine Sulfate

Hydrazine sulfate, $H_2NNH_2{\cdot}H_2SO_4$, is a white powder that is very soluble in hot water and insoluble in alcohol, which decomposes at its boiling point. Hydrazine sulfate is used in chemical manufacturing and as a fungicide and germicide.

Corrosion Behavior of Various Metals and Alloys in Hydrazine Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Glycerol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	Concentrated	Boiling	...	Resistant	...	253
430	S43000	...	...	Concentrated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Concentrated	Boiling	...	Resistant	...	253
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Concentrated	Boiling	...	Resistant	...	253
Carpenter 20	...	...	Soap processing; field or pilot plant test; no aeration; no agitation. Glycerine saturated with salt (Wooster-Sanger evaporator)	15-80	60-104 (140-220)	91 d	0.003 (0.1) max	Crevice attack	89
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	Boiling	...	Resistant	...	253

Glycolic Acid

Glycolic acid, $CH_2OHCOOH$, also known as hydroxyacetic acid, is composed of colorless deliquescent leaflets that decompose at approximately 78 °C (172 °F). It is soluble in water, alcohol, and ether. Glycolic acid is used in dyeing, tanning, electropolishing, and in foodstuffs. It is produced by oxidizing glycol with dilute nitric acid.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys 3003 and 5154 were reported to be attacked by glycolic acid at 100 °C (212 °F) in laboratory tests. Aluminum alloy containers have been used to ship and store glycolic acid solutions.

Corrosion Behavior of Various Metals and Alloys in Glycolic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Zr702	R60702	...	...	...	40 (104)	...	0.13 (5) max	...	15

Hydrazine Sulfate

Hydrazine sulfate, $H_2NNH_2{\cdot}H_2SO_4$, is a white powder that is very soluble in hot water and insoluble in alcohol, which decomposes at its boiling point. Hydrazine sulfate is used in chemical manufacturing and as a fungicide and germicide.

Corrosion Behavior of Various Metals and Alloys in Hydrazine Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrazine Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
304	S30400	...	...	10	Boiling	...	Questionable	...	253
304L	S30403	...	...	10	Boiling	...	Questionable	...	253
304LN	S30453	...	...	10	Boiling	...	Questionable	...	253
316	S31600	...	...	10	Boiling	...	Questionable	...	253
316F	S31620	...	...	10	Boiling	...	Questionable	...	253
316L	S31603	...	...	10	Boiling	...	Questionable	...	253
316LN	S31653	...	...	10	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	10	Boiling	...	Questionable	...	253
317L	S31703	...	...	10	Boiling	...	Questionable	...	253
317LN	S31725	...	...	10	Boiling	...	Questionable	...	253
321	S32100	...	...	10	Boiling	...	Questionable	...	253
329	S32900	...	...	10	Boiling	...	Questionable	...	253
347	S34700	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	10	Boiling	...	Questionable	...	253
F51	S31803	...	...	10	Boiling	...	Questionable	...	253

Hydrobromic Acid

Hydrobromic acid, HBr, is a solution of hydrogen bromide in water, usually 40%. It is a strongly acidic liquid, which fumes when at a saturated concentration. Hydrobromic acid is used in medicine, analytical chemistry, and in the synthesis of alkyl and inorganic bromides. The bromides are usually soluble with the exception of the copper, gold, silver, mercury, lead, and thallium bromides and the heavy alkali ions with many bromo-complex anions.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Niobium. Niobium is resistant to hydrobromic acid at all concentrations and temperatures below 100 °C (212 °F).

Silver. The exposure of silver-lined reaction vessels to hydrobromic acid is limited to a concentration of 14% and room temperature.

Rhodium. In wrought or cast form, rhodium is attacked slowly at 100 °C (212 °F) by hydrobromic acid.

Tantalum. Tantalum is not attacked by hydrobromic acid or any of the bromides at ordinary temperatures.

Tin. Hot hydrobromic acid rapidly attacks tin.

Zirconium. Zirconium has good resistance against hydrobromic acid. Boiling hydrobromic acid in concentrations of 20, 45, and 48% registered corrosion rates of less than 0.13 mm/yr (5 mils/yr). Zirconium also exhibits a low pitting tendency in 1*N* hydrobromic acid.

Corrosion Behavior of Various Metals and Alloys in Hydrobromic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrobromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
Gold	P00016	...	Specific gravity 1.7	...	Room	...	0.05 (2) max	...	8
Iridium	...	...	Specific gravity 1.7	...	100 (212)	...	Resistant	...	29
Lead	L50045	...	...	10-70	24 (75)	...	1.3 (50) min	...	95
Osmium	...	...	Specific gravity 1.7	...	100 (212)	...	1.8 (72)	...	17
Palladium	P03980	...	Fuming	...	Room	...	161.2 (6346)	...	17
Rhodium	P05990	...	Fuming	...	100 (212)	...	2.2 (87)	...	29
Ruthenium	...	...	...	62	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	14 max	Room	...	0.05 (2) max	...	4
Silver	P07010	...	...	14 max	Room	...	0.05 (2) max	...	4
Tin	...	...	...	50	100 (212)	...	Poor	...	94
Tin	...	...	...	50	20 (68)	...	Poor	...	94
Tin	...	...	...	50	60 (140)	...	Poor	...	94
Refractory metals and alloys									
Hafnium	...	...	...	40	...	10 d	0.025 (1.0)	Pitting	11
Zr702	R60702	...	BP 125°C (257°F)	48	Boiling	...	0.13 (5) max	Shallow pits	15
Zr702	R60702	...	Plus 50% acetic acid (glacial)	24	Boiling	...	0.025 (1) max	Shallow pits	15
Zr705	R60705	...	BP 125°C (257°F)	48	Boiling	...	0.13 (5) max	...	15
Zr705	R60705	...	Plus 50% acetic acid (glacial)	24	Boiling	...	0.025 (1) max	...	15
Stainless steels									
304	S30400	...	...	All	21 (70)	...	Poor	...	121
304	S30400	...	Chemical processing (distillation); field or pilot plant test; no aeration; slight to moderate agitation. Various concentrations, decomposition products of ethylene dibromide	...	93-100 (200-212)	37 d	0.45 (18)	Severe pitting; crevice attack	89
304	S30400	...	Chemical processing (distillation); field or pilot plant test; no aeration; no agitation. Plus hydrochloric acid, crude ethylene dibromide	...	75 (168)	55 d	0.69 (27)	Moderate pitting; crevice attack	89
316	S31600	...	...	All	21 (70)	...	Poor	...	121

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrobromic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing (distillation); field or pilot plant test; no aeration; no agitation. Plus hydrochloric acid, crude ethylene dibromide	...	75 (168)	55 d	0.15 (5.8)	Moderate pitting; crevice attack	89
316	S31600	...	Chemical processing (distillation); field or pilot plant test; no aeration; slight to moderate agitation. Various concentrations, decomposition products of ethylene dibromide	...	93-100 (200-212)	37 d	0.45 (18)	Severe pitting; crevice attack	89
430	S43000	...	...	All	21 (70)	...	Poor	...	121
410	S41000	...	...	All	21 (70)	...	Poor	...	121

Corrosion Rates of Tantalum and Niobium Exposed to Hydrogen-Bubbled 47 wt% Hydrobromic Acid Solutions

Temperature (C)	Test Period (Day)	Corrosion Rate Tantalum (mdd)	Tantalum (μm/y)	Niobium (mdd)	Niobium (μm/y)
50	8	ND(1)	ND	0.4 (ND)(2)	1.6 (ND)
50	14	ND	ND	0.3 (0.3)	1.2 (1.1)
75	8	ND	ND	2.9 (2.9)	12.2 (12.6)
100	8	1.0 (0.6)	2.2 (1.3)	18.3	77.7
100	14			14.4	61.2
124	8	1.6	3.5		
124	22	0.7	1.5		

(1) ND = not determined. (2) Values in parentheses represent the corrosion rates determined by analysis of the test solutions.
Source: I. Uehara, T. Sakai, *et al.*, The Corrosion Behavior of Tantalum and Niobium in Hydrobromic Acid Solutions, *Corrosion*, Vol 42, Aug 1986, 495.

Effects of Temperature and Bromine Concentrations on the Corrosion Rates of Tantalum and Niobium in 47 wt% Hydrobromic Acid Solutions

Temperature (C)	Test Period (Day)	Br_2 (mol/dm^3)	Corrosion Rate Tantalum (mdd)	Tantalum (μm/y)	Niobium (mdd)	Niobium (μm/y)
75	13	0.002	ND(1)		1.2 (1.2)(2)	4.9 (5.2)
75	13	0.021	ND		0.2 (0.5)	1.0 (2.0)
75	13	0.110	ND		0.2 (0.4)	0.6 (1.6)
100	8	0.002	0.3 (0.3)	0.5 (0.6)	2.6 (2.7)	11.2 (11.5)
100	8	0.008	ND		2.0 (2.0)	8.5 (8.4)
100	8	0.021	ND		1.9 (2.0)	8.0 (8.4)
100	9	>0.5			1.0	4.3

(1) ND = not determined. (2) Values in parentheses represent the corrosion rates determined by analysis of the test solutions.
Source: I. Uehara, T. Sakai, *et al.*, The Corrosion Behavior of Tantalum and Niobium in Hydrobromic Acid Solutions, *Corrosion*, Vol 42, Aug 1986, 495.

Hydrochloric Acid

Hydrochloric acid, HCl, also known as muriatic acid, is a poisonous, corrosive, hazardous liquid that reacts with most metals to form explosive hydrogen gas and causes severe burns and irritation of eyes and mucous membranes. It is made by absorbing hydrogen chloride in water. Most acid is the by-product of chlorination. Pure acid is produced by burning chlorine and hydrogen. Hydrochloric acid is available in technical, recovered, food-processing, and reagent grades. Frequently, the commercial grades are slightly yellow as a result of impurities, notably dissolved iron. Reagent grade, which normally contains about 37.1% hydrochloric acid, is perfectly clear and colorless.

Hydrochloric acid is an important mineral acid with many uses, including acid pickling of steel, acid treatment of oil wells, chemical cleaning and processing, ore reduction, production of numerous chlorides, production of chlorine, and food processing.

Concentrated hydrochloric acid is transported and stored in rubber-lined tanks, although custom-fabricated polyester-reinforced thermoset plastic storage tanks have been used. Pipelines are usually plastic-lined steel. Processes involving aqueous acid are commonly carried out in glass-lined steel equipment. Nonmetallic materials are normally preferred because of the corrosive action of this strongest of acids on most metals.

Candidate metals and alloys for handling hydrochloric acid are judged to be those with corrosion rates under 0.5 mm/yr (20 mils/yr) when exposed to uncontaminated hydrochloric acid. In practice, contamination is not uncommon and can be catastrophic. Selection of a candidate metal should be based on extensive corrosion testing or, preferably, field experience, using the grade of acid that will be available.

Effect of Impurities. Hydrochloric acid recovered from the manufacture of fluorocarbons may contain trace amounts of hydrofluoric acid (HF). It has been reported that such acids may contain more than 0.5% HF. Commercial suppliers remove most of the fluoride from hydrochloric acid by selective absorption, and it is unlikely that a customer would receive acid containing as much as 0.5%, but glass-lined steel and the refractory metals, such as zirconium, niobium, tantalum, and titanium (but not molybdenum), have very low tolerance levels for fluorides. Zirconium is reported to tolerate less than 10 ppm. Tantalum may tolerate 10 ppm or more. The limits are undefined except for a few specific cases, and it is best to consider all of these metals and glass-lined steel to be essentially nonresistant to fluorides and to know the source and specification limits of the acid if these materials are used. Other species that can be oxidizing include palladium and cobalt.

The presence of ferric ions in hydrochloric acid has a profound effect on the corrosion of many metals and alloys otherwise resistant to hydrochloric acid. Nickel-base alloys, including Hastelloy B-2, the copper alloys, and unalloyed zirconium, are affected. Although the acid specification may be low in iron, acid can easily become contaminated during shipment and handling. The presence of nitric acid will result in high corrosion rates of low-chromium alloys such as Hastelloy C-276 and B-2.

Cupric ions have an accelerating effect on the corrosion of many metals that is similar to that of ferric ions. Like ferric ions, cupric ions can cause pitting and stress-corrosion cracking of zirconium. The presence of cupric ions can also lead to the autocatalytic acceleration of nickel-copper and copper-nickel alloys. It is unlikely that commercial acid would contain cupric salts. This is more of a problem of in-process contamination by exposure of copper-containing metals or introduction as an impurity in a chemical or raw material used in the process.

Aeration. Although less damaging than the presence of oxidizing metal salts, aeration accelerates the corrosion of many metals.

Chlorine. Contamination accelerates the corrosion of all metals except unalloyed tantalum and noble metals; however, unalloyed titanium can be protected by the presence of chlorine in dilute hydrochloric acid. Chlorine may be present in acid recovered from a chlorination process, but it would be removed before commercial sale.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. Use of cast irons is relatively limited in hydrochloric acid. Unalloyed cast iron is unsuitable for any hydrochloric acid service. Rapid corrosion occurs at a pH of 5 or lower, particularly if appreciable velocity is involved. Aeration or oxidizing conditions, such as the presence of metallic salts, result in rapid destructive attack of unalloyed cast irons even in very dilute hydrochloric acid solutions.

High-nickel austenitic cast irons offer some resistance to all hydrochloric acid concentrations at room temperature or below. High-chromium cast irons are not suitable for hydrochloric acid service.

High-silicon cast irons offer the best resistance to hydrochloric acid of any cast iron. When alloyed with 4 to 5% Cr, high-silicon cast iron is suitable for all concentrations of hydrochloric acid to 28 °C (80 °F). When high-silicon cast iron is alloyed with chromium, molybdenum, and higher silicon levels, the temperature for use can be increased. A high-silicon iron alloyed with small amounts of molybdenum, chromium, and copper has good resistance to all concentrations of hydrochloric acid up to temperatures as high 95 °C (200 °F). It is one of the few metals commonly used for pumps and valves in handling commercial grades of acid. In concentrations up to 20%, ferric ions or other oxidizing agents inhibit corrosion attack on high-silicon iron alloyed with chromium. At over 20% acid concentration, oxidizers accelerate attack on the alloy. As in sulfuric acid, corrosion rates in high-silicon cast iron are initially high in the first 24 to 48 h of exposure then decrease to very low steady-state rates. Fluoride impurities are damaging.

Carbon and Alloy Steels. Carbon and alloy steels are unsuitable for exposure to hydrochloric acid except during acid cleaning. Repeated acid cleaning of carbon steel is likely to result in significant pitting. Hard-

ened alloy steels are subject to hydrogen embrittlement. This problem is aggravated by corrosion inhibitors, because they generally suppress the cathodic reaction, promoting atomic hydrogen absorption rather than molecular hydrogen evolution. Therefore, the jackets of glass-lined vessels should not be cleaned with hydrochloric (or sulfuric) acid to avoid hydrogen spalling.

Stainless Steels. The commonly used austenitic stainless steels, such as types 304 and 316, are not resistant to hydrochloric acid at any concentration and temperature. At ambient temperatures and above, corrosion rates are high. Nickel, molybdenum, and to a lesser extent copper impart some resistance to dilute acid, but pitting, local attack, and stress-corrosion cracking may result. Subambient temperatures will slow the corrosion rate, but will invite stress-corrosion cracking. Type 316 stainless steel has been known to crack in 5% hydrochloric acid at 0 °C (32 °F). At high corrosion rates (>0.25 mm/yr, or 10 mils/yr), stress-corrosion cracking is unlikely to occur. However, the corrosion products, particularly $FeCl_3$, will cause cracking. Chlorides can penetrate and destroy the passivity (oxide film) that is responsible for the corrosion resistance of stainless steels, and the corrosion engineer should resist every attempt to use stainless steels in environments containing chlorides.

The standard ferritic stainless steels, such as types 410 and 430, should not be considered, because their corrosion resistance to hydrochloric acid is lower than that of carbon steel. An exception is 29-4-2 stainless steel, which reportedly resists up to 1.5% hydrochloric acid to the boiling point and remains passive. However, it is not suitable at higher concentrations, and the alloy is susceptible to stress-corrosion cracking, although its resistance is reported to be high.

Some stainless steels—such as 20Cb-3, with its high nickel content (32 to 38%), 2 to 3% Mo, and 3 to 4% Cu—resist dilute hydrochloric acid at ambient temperatures. However, 20Cb-3 is susceptible to pitting and crevice attack in acid chlorides and should be used with caution.

Corrosion studies of sintered austenitic stainless steels have shown that the corrosion resistance improves significantly with increasing density in acidic environments such as dilute hydrochloric acid.

Aluminum. Aluminum is corroded by hydrochloric acid. The rate of attack increases with acid concentration and temperature. Metal purity plays a significant role in the degree of attack by hydrochloric acid. Increasing purity of the aluminum decreases the rate of attack by hydrochloric acid significantly. Inhibitors can be effective in reducing the corrosive effects of hydrochloric acid, particularly in dilute (<10%) solutions. Such inhibited acid has been used to clean aluminum equipment and containers.

Cemented Carbides. The corrosion rates of various cemented carbide compositions in warm (50 °C, or 120 °F) acids were investigated. From the rates observed fro straight WC-Co compositions ion hydrochloric acid, even though lower than the rates in H_2SO_4 and HNO_3, it was obvious that these compositions are not suitable for use in warm or hot hydrochloric acid solutions. The TiC-6.5Ni-5Mo composition exhibited moderately good resistance to hydrochloric acid, and several of the binderless compositions and a TaC-base cemented carbide exhibited very acceptable resistance.

Copper. Copper and copper alloys have limited utility in hydrochloric acid service (dilute concentrations only) because they are so sensitive to velocity, aeration, and oxidizing impurities. However, copper is one of the few common metals above hydrogen in the electromotive force (emf) series, and under reducing conditions, it can experience low corrosion rates. An example is the use of silicon bronze (CDA C65500) agitators and hardware in the manufacture of $ZnCl_2$ by dissolving zinc in hydrochloric acid, with the evolution of hydrogen.

Typical corrosion rates for silicon bronze in hydrochloric acid under nonaerated nonoxidizing conditions are 0.08 to 0.1 mm/yr (3 to 4 mils/yr) in up to 20% acid and 0.5 mm/yr (20 mils/yr) in concentrated acid at 25 °C (75 °F). At 70 °C (160 °F), rates are approximately 1 mm/yr (40 mils/yr) in up to 20% acid and over 6.4 mm/yr (250 mils/yr) in concentrated (35 to 37%) acid.

Aluminum bronzes are generally suitable for service in hydrochloric acid. Phosphor bronzes, although they are resistant to most nonoxidizing acids, are not suitable for hydrochloric acid service.

The corrosion rate of copper nickels in 2*N* hydrochloric acid at 25 °C (75 °F) may range from 2.3 to 7.6 mm/yr (90 to 300 mils/yr), depending on the degree of aeration and other factors. Specimens of C71000 (copper nickel, 20%) in stagnant 1% hydrochloric acid solutions at room temperature corrode at a rate of 305 μm/yr (12 mils/yr); in 10% hydrochloric acid, the rate is 790 μm/yr (31 mils/yr).

Lead. Lead has fair corrosion resistance to dilute hydrochloric acid (up to 15%) at 24 °C (75 °F); the corrosion rate increases at higher concentrations and at higher temperatures. The presence of 5% ferric chloride also accelerates corrosion. The corrosion rates of chemical lead and 6% antimonial lead in hydrochloric acid are retarded by the presence of H_2SO_4.

Metallic Glasses. The first published information of the corrosion behavior of metallic glasses, which appeared in 1974, concerned the Fe-Cr-P-C alloy system. A comparison was made of the corrosion rates of $Fe_{70}Cr_{10}P_{13}C_7$ and $Fe_{65}Cr_{10}Ni_5P_{13}C_7$ metallic glasses and a typical AISI type 304 stainless steel in hydrochloric acid of various concentrations at 30 °C (85 °F). The corrosion rates, calculated from gravimetric measurements, were relatively large for the stainless steel because of pitting attack, but the rates for the metallic glasses were so low that they could not be detected even after immersion for 168 h. This early work illuminates the distinct differences in corrosion behavior between crystalline stainless steel and iron-base metal-metalloid glasses.

A study was done comparing the corrosion rates of crystalline Fe-Cr alloys and amorphous Fe-Cr-P-C alloys in hydrochloric acid as a function of chromium concentration. At low chromium levels, the amorphous alloy corroded at a higher rate than the crystalline material. However, at slightly higher chromium levels (4 at.%), there was a significant decrease in the corrosion rate of the glassy alloy, but the crystalline material remained essentially unchanged. At an intermediate level of 8 at.% Cr, no corrosion of the glassy alloy was detected by weight loss experiments after immersion for 168 h. It was also found that the concentration of hydrochloric acid, which has a profound effect on corrosion behavior of crystalline alloys, had no effect on corrosion of the glassy Fe-Cr-P-C or Fe-Ni-Cr-P-C alloy systems, which exhibited no weight loss after exposure for 168 h.

The effect of chromium concentration on the corrosion behavior or amorphous iron-, nickel-, and cobalt-base alloys in 1*N* hydrochloric acid was investigated. In all cases, the corrosion rate decreased with increasing chromium concentration. In addition, the Fe-Cr-P-C alloy system, which exhibited the highest corrosion rate at low chromium contents, experienced no weight loss in immersion tests with a chromium concentration of as little as 8 at.%. Glassy $Fe_{73}Cr_7P_{15}B_5$ passivated spontaneously in 1*N* hydrochloric acid. Surface analysis by x-ray photoelectron spectroscopy showed that chromium and phosphorus

were enriched and that nickel became depleted in the alloy substrate beneath the passive film.

The tendency of glassy $Fe_{40}Ni_{40}P_{14}B_6$ to undergo stress-corrosion cracking and hydrogen embrittlement in acidic electrolytes was studied. Elastically stressed specimens cathodically polarized in 1*M* hydrochloric acid failed by hydrogen embrittlement, whereas specimens anodically polarized in 1*M* hydrochloric acid failed by stress-corrosion cracking. These specimens were covered by an iron oxide film, and selective leaching (dealloying) of nickel from pits and cracks occurred.

Molybdenum increases the pitting resistance of glassy alloys and crystalline steels in hydrochloric acid. Addition of molybdenum to glassy Fe-Mo-$xP_{13}C_7$ alloys suppresses pitting and decreases the critical current density for passivation and the passive current density. As little as 4 at.% Mo prevents pitting in 1*N* hydrochloric acid, and small additions of molybdenum are more effective than chromium in decreasing corrosion rates.

Nickel. Commercially pure nickel (Nickel 200 and 201) and nickel-copper alloys (Monel 400) have room-temperature corrosion rates below 0.25 mm/yr (10 mils/yr) in air-free hydrochloric acid at concentrations up to 10%. In hydrochloric acid concentrations of less than 0.5%, these alloys have been used at temperatures up to about 200 °C (390 °F). Monel 400 has been used at concentrations below 20% at ambient temperatures under air-free conditions and under 10% concentration aerated, but penetration rates generally exceed 0.25 mm/yr (10 mils/yr) and may approach 1 mm/yr (40 mils/yr). Oxidizing agents, such as cupric and chromate ions, or aeration, increase the corrosion rate considerably. Under these conditions nickel-chromium-molybdenum alloys such as Inconel 625 or Hastelloy C-276 offer better corrosion resistance. They can be passivated by the presence of oxidizing agents.

Increasing the temperature affects the corrosion rate of Nickel 200 more than that of Monel 400 in 5% hydrochloric acid. When hydrochloric acid is formed by hydrolysis of chlorinated hydrocarbons, acid concentrations are often less than 0.5%. Under these conditions, Nickel 200 and Monel 400 have found application at temperatures below 200 °C (390 °F).

Inconel 600, although it has useful resistance to cold dilute hydrochloric acid, exhibits corrosion resistance that is inferior to that of Nickel 200 and Monel 400. However, this alloy is useful in handling wet halogenated solvents, because it has little, if any, catalytic effect on hydrolysis.

Inconel 825, Hastelloy G, and Inconel 625 contain appreciable amounts of chromium and increasing amounts of molybdenum, and they have useful resistance to all concentrations of hydrochloric acid below 40 °C (100 °F). Inconel 625 has good resistance to concentrated reagent-grade acid at ambient temperatures.

These alloys have good resistance to dilute (<5%) acid at higher temperatures and are less affected by aeration than Nickel 200 and Monel 400. They are all very resistant to chloride stress-corrosion cracking. Resistance to pitting and crevice corrosion in acid chloride solutions improves with increasing chromium and molybdenum contents. Thus, Inconel 625 (22Cr-9Mo) is more resistant than Hastelloy G (22Cr-6.5Mo), which in turn is more resistant than Inconel 825 (21Cr-3Mo).

The most corrosion resistant of the nickel-base alloys to hydrochloric acid are Hastelloy B-2 (Ni-28Mo) and Hastelloy C-276 (Ni-16Cr-15.5Mo). Hastelloy B-2 is one of the few metals with a corrosion rate under 0.5 mm/yr (20 mils/yr) in all concentrations and at temperatures up to the atmospheric boiling point in nonaerated acid in the absence of oxidizing agents.

Accordingly, this alloy is used in a variety of processes involving hot hydrochloric acid or nonoxidizing chloride salts that are hydrolyzed to produce hydrochloric acid. Hastelloy B-2 experiences two isocorosion curves—one at high temperatures near the boiling point and one at low temperature. This is due to variations in the oxygen content of the solutions. At the higher temperatures, the oxygen solubility is lower, and therefore, the corrosion rate is lower. The major weakness of the alloy is that its corrosion resistance decreases dramatically under oxidizing conditions. Chromium-containing alloys such as Hastelloy C-276 or Inconel 625 can be passivated when oxidizers are present and thus display much lower corrosion rates.

Hastelloy C-276 has excellent corrosion resistance (<0.13 mm/yr, or 5 mils/yr) in all concentrations of hydrochloric acid at room temperatures and good resistance (<0.5 mm/yr, or 20 mils/yr) to all concentrations up to 50 °C (120 °F). At concentrations under 10%, its resistance often exceeds that of Hastelloy B-2. Oxygen and strong oxidizing agents accelerate corrosion, although markedly less than for Hastelloy B-2.

Niobium. Niobium is resistant to hydrochloric acid in all concentrations at temperatures below 100 °C (212 °F).

Gold. Refined gold is extremely resistant to all concentrations of hydrochloric acid at temperatures up to and above the atmospheric boiling point.

Iridium. Iridium, although resistant to anodic corrosion in aqueous electrolytes, may be attacked in aqueous hydrochloric acid (and potassium cyanide) under the action of an alternating current.

Osmium. Osmium is resistant to hydrochloric acid.

Palladium. Palladium is readily corroded anodically in hydrochloric acid solutions. However, palladium alloys containing more than 20% gold are resistant to hydrochloric acid.

Platinum. Refined platinum is almost as resistant to hydrochloric acid as gold. It is slightly attacked by 36% acid at 100 °C (212 °F), the point at which gold shows no appreciable attack. A 10% addition of rhodium to platinum reduces the corrosion rate in 36% hydrochloric acid at 100 °C from 0.2 mm/yr (50 mils/yr) to zero. As an anode, platinum will resist attack in a wide variety of alkaline, neutral, and mildly acidic solutions, but is attacked by strong solutions.

Rhodium. In wrought or cast form, rhodium remains unattacked at 100 °C (212 °F) by concentrated hydrochloric acid.

Silver. Silver forms a protective chloride film in hydrochloric acid and thus is resistant to this acid as long as the film is not dissolved or disturbed. Results can be unsatisfactory under strongly aerating conditions when acid concentration and temperature are increased. At ambient temperatures, in the absence of oxidizing agents, silver resists hydrochloric acid in all concentrations, exhibiting a corrosion rate of less than 0.025 mm/yr (<1 mil/yr) at concentrations of 20% or lower. At the boiling point, corrosion rates vary from 0.025 mm/yr (1 mil/yr) at 5% to 0.5 mm/yr (20 mils/yr) at 20%. Increases in temperature, aeration, and velocity will increase corrosion rates.

Tantalum. Tantalum and its alloys are the most resistant to hydrochloric acid. Specific corrosion tests and many industrial applications show that tantalum is completely inert to hydrochloric acid in all concentrations under atmospheric pressure to at least 90 °C (195 °F). This has been demonstrated by long industrial experience. For example, bayonet heat-

ers fabricated from tantalum with a wall thickness as thin as 0.33 mm (0.013 in.) have been in continuous industrial use in hydrochloric acid distilling units for over 20 years without being attacked.

Tantalum resists concentrations below 25% up to 190 °C (375 °F) and concentrations to 37% at temperatures to 150 °C (300 °F). It was found that tantalum is embrittled by concentrations of 25% or higher at 190 °C (375 °F). Corrosion rates at that temperature were less than 0.025 mm/yr (<1 mil/yr) at 25% concentration or less, 0.01 mm/yr (3.9 mils/yr) at 30%, and 0.29 mm/yr (11.6 mils/yr) at 37%. Embrittlement was most pronounced in 37% acid. It also was found that corrosion and embrittlement could be avoided by coupling tantalum with platinum. This discovery formed the basis for the later development of the titanium-palladium alloy. The possibility of hydrogen embrittlement should be considered whenever tantalum is used for handling concentrated solutions of hydrochloric acid above the boiling point of the acid. This tendency was not noted at or below the boiling point.

Additions of HNO_3 and ferric or cupric chlorides ($FeCl_3$ or $CuCl_2$) to hydrochloric acid tend to improve corrosion resistance of tantalum. Tantalum, like zirconium and titanium, is embrittled by the absorption of atomic hydrogen. This occurs if the metal is corroded in a nonoxidizing chemical or if it becomes the cathode of an electrolytic cell. For example, it is possible to embrittle tantalum plugs in a glass-lined vessel, if the vessel is equipped with an agitator of a metal lower in the emf series.

Researchers in other tests also found that tantalum and substitutional tantalum-base alloys became hydrogen embrittled in concentrated hydrochloric acid at 150 °C (300 °F). Corrosion rates of Ta-Nb alloys were conducted in hot and cold concentrated hydrochloric acid on alloys having various proportions of tantalum and niobium. The corrosion rate increased roughly in proportion to the niobium content of the alloy. Even though the 95Ta-5Nb alloy exhibited excellent resistance in all exposures, the attack was three times that obtained on pure tantalum.

The corrosion behavior of alloys in the Ti-Ta-Nb system in 5% hydrochloric acid at 100 °C (212 °F) was investigated. The corrosion rate dropped by a factor of 1.5 to 2 times less than that of titanium, with a total of 15 to 20% Nb or Ta in the alloy. At 20 to 30% additions of these elements, the corrosion rate dropped by a factor of 10 to 70 times less than that of titanium. Tantalum increased the corrosion resistance of the alloys more effectively than niobium.

The role of the structural factor in increasing the corrosion resistance of the titanium-tantalum-chromium and titanium-chromium alloys in a 5% hydrochloric acid solution at 100 °C (212 °F) was demonstrated. The corrosion rate of quenched alloys was 2 to 10 times or more lower than that of annealed alloys. As the tantalum content increases, the corrosion rate decreases for both quenched and annealed alloys. The ternary alloys with a tantalum to chromium ratio of 3:1 and binary titanium-tantalum alloys with 20% more tantalum were found to have good corrosion resistance.

Titanium. Although titanium has limited resistance to hydrochloric acid, it is, unlike other metals, passivated rather than corroded by the presence of dissolved oxygen, ferric and cupric ions, nitrates, chromates, chlorine, and other oxidizing impurities. In commercial applications involving hot dilute acid, enough impurities are often present to provide a high degree of protection. For example, the corrosion rate of unalloyed titanium in boiling 4% hydrochloric acid was lowered from 21.4 mm/yr (843 mils/yr) to 0.01 mm/yr (0.4 mils/yr) by the addition of 0.2% $FeCl_3$. No titanium alloy has resistance to concentrated grades of hydrochloric acid.

Zirconium. The resistance of zirconium to corrosion by hydrochloric acid exceeds that of most metals (exceptions are tantalum and such noble metals as gold and platinum). Corrosion rates are less than 0.13 mm/yr (5 mils/yr) at all concentrations up to the atmospheric boiling point and above, and aeration does not have an appreciable effect. Moreover, zirconium is not as susceptible to hydrogen embrittlement in hydrochloric acid as tantalum. In one study, tantalum lost 33% and 18% of its ductility after 1000 h in 11*M* hydrochloric acid and 11*M* hydrochloric acid + 7% gallium chloride ($GaCl_3$), respectively, at 70 °C (160 °F). Under the same testing conditions, zirconium remained unattacked and retained 100% of its ductility.

Although hydrochloric acid is highly reducing, the anodic polarization curves of zirconium still do not have the active region. This corrosion property explains the resistance of zirconium to crevice corrosion in chloride-containing environments. However, zirconium can suffer pitting and/or stress-corrosion cracking when it is anodically polarized to a potential at or exceeding the pitting potentials. The same types of corrosion problems can be developed in hydrochloric acid when strong oxidizing ions, such as ferric ions, are present. The presence of ferric ions polarizes the zirconium surface to a potential exceeding the pitting potential. Thus, local breakdown of the passive surface at preferred sites occurs, and a condition develops that favors pitting and/or cracking. Maintaining zirconium at a potential in its passive region (arbitrarily set at 50 to 100 mV below the corrosion potential) can counteract the detrimental effects resulting from the presence of ferric ions.

It is important to avoid galvanic effects when connecting zirconium to other metals immersed in an electrolyte, because zirconium, like all the reactive metals, is sensitive to hydrogen embrittlement when it is the cathode of an electrochemical cell.

Hafnium. Hafnium is resistant to dilute hydrochloric acid.

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
1020 steel	G10200	...	Lab test. Plus 60% water	40	200 (392)	15 d	0.05 (1.8)	...	182
1020 steel	G10200	...	Lab test. Plus 60% water	40	300 (570)	15 d	0.7 (28)	...	182
1020 steel	G10200	...	Lab test. Plus 60% water	40	400 (752)	15 d	0.3 (13)	...	182
1020 steel	G10200	...	Lab test. Plus 60% water	40	500 (932)	15 d	2.1 (83)	...	182
4130 steel	G41300	...	Acidizing fluid, with inhibitor	15	120	12 h	.03 (1.3)	Pitting	207

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
4130 steel	G41300	...	Lab test. Plus 60% water	40	200 (392)	15 d	0.05 (2.0)	...	182
4130 steel	G41300	...	Lab test. Plus 60% water	40	300 (570)	15 d	0.9 (34)	...	182
4130 steel	G41300	...	Lab test. Plus 60% water	40	400 (752)	15 d	0.4 (16)	...	182
4130 steel	G41300	...	Lab test. Plus 60% water	40	500 (932)	15 d	1.7 (67)	...	182
9 Cr steel	S50400	...	Acidizing fluid, with inhibitor	15	120	12 h	.44 (17.5)	...	207
ASTM 335, grade P11 (1.5Cr-0.25Mo)	K11597	...	1.4N	...	45 (115)	3 h	4 (160)	...	31
ASTM 335, grade P22 (2Cr-1Mo)	K21590	...	1.4N	...	45 (115)	3 h	10 (390)	...	31
ASTM 335, grade P5 (5Cr-0.5Mo)	K51545	...	1.4N	...	45 (115)	3 h	3 (120)	...	31
ASTM 335, grade P9 (10Cr-1Mo)	S50400	...	1.4N	...	45 (115)	3 h	6 (240)	...	31
ASTM A106 carbon steel	G10100	...	1.4N	...	45 (115)	3 h	23 (910)	...	31
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Ampco 8, aluminum bronze	C61300	...	...	15 min	...	...	0.5 (20) min	...	96
Ampco 8, aluminum bronze	C61300	...	Conditions such as aeration or temperature could restrict use	To 15	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Copper	...	...	...	Concentrated	...	...	0.75 (30)	...	28
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Irons and alloys									
Armco iron	...	...	1.4N	...	45 (115)	3 h	13 (510)	...	31
Miscellaneous									
85WC-15Co	...	...	...	10	22 (72)	48 h	0.05 (2.1)	...	34
85WC-15Co	...	...	...	10	22 (72)	48 h	0.06 (2.5)	...	34
94WC-6Co	...	...	...	10	22 (72)	48 h	0.04 (1.6)	...	34
94WC-6Ni	...	...	...	10	22 (72)	48 h	0.01 (0.5)	...	34
Chemical lead	L51120	...	...	1	24 (75)	...	0.6 (24)	...	131
Chemical lead	L51120	...	...	1	24 (75)	...	0.6 (24)	...	254
Chemical lead	L51120	...	...	10	24 (75)	...	0.6 (22)	...	135
Chemical lead	L51120	...	...	10	24 (75)	...	0.6 (22)	...	254
Chemical lead	L51120	...	...	15	24 (75)	...	0.8 (31)	...	135
Chemical lead	L51120	...	...	15	24 (75)	...	0.8 (31)	...	254
Chemical lead	L51120	...	...	20	24 (75)	...	1.9 (74)	...	254

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Chemical lead	L51120	...	...	25	24 (75)	...	4.8 (190)	...	254
Chemical lead	L51120	...	...	35	24 (75)	...	8.8 (350)	...	254
Chemical lead	L51120	...	...	5	24 (75)	...	0.4 (16)	...	131
Chemical lead	L51120	...	...	5	24 (75)	...	0.4 (16)	...	254
Chemical lead	L51120	...	With 1% sulfuric acid	9	24 (75)	...	0.5 (18)	...	254
Chemical lead	L51120	...	With 1% sulfuric acid	9	66 (150)	...	1.2 (47)	...	254
Chemical lead	L51120	...	With 10% sulfuric acid	20	24 (75)	...	2.2 (86)	...	254
Chemical lead	L51120	...	With 10% sulfuric acid	20	66 (150)	...	3.0 (120)	...	254
Chemical lead	L51120	...	With 15% sulfuric acid	15	24 (75)	...	1.0 (41)	...	254
Chemical lead	L51120	...	With 15% sulfuric acid	15	66 (150)	...	1.9 (74)	...	254
Chemical lead	L51120	...	With 20% sulfuric acid	10	24 (75)	...	0.4 (17)	...	254
Chemical lead	L51120	...	With 20% sulfuric acid	10	66 (150)	...	1.1 (42)	...	254
Chemical lead	L51120	...	With 25% sulfuric acid	25	24 (75)	...	3.0 (120)	...	254
Chemical lead	L51120	...	With 25% sulfuric acid	5	24 (75)	...	0.3 (10)	...	254
Chemical lead	L51120	...	With 25% sulfuric acid	5	66 (150)	...	0.6 (22)	...	254
Chemical lead	L51120	...	With 3% sulfuric acid	7	24 (75)	...	0.4 (16)	...	254
Chemical lead	L51120	...	With 3% sulfuric acid	7	66 (150)	...	1.1 (45)	...	254
Chemical lead	L51120	...	With 30% sulfuric acid	20	24 (75)	...	2.1 (84)	...	254
Chemical lead	L51120	...	With 35% sulfuric acid	15	24 (75)	...	1.7 (66)	...	254
Chemical lead	L51120	...	With 40% sulfuric acid	10	24 (75)	...	1.6 (65)	...	254
Chemical lead	L51120	...	With 45% sulfuric acid	5	24 (75)	...	1.6 (62)	...	254
Chemical lead	L51120	...	With 5% ferric chloride	10	24 (75)	...	1.0 (41)	...	254
Chemical lead	L51120	...	With 5% ferric chloride	15	24 (75)	...	2.2 (88)	...	254
Chemical lead	L51120	...	With 5% ferric chloride	20	24 (75)	...	3.8 (150)	...	254
Chemical lead	L51120	...	With 5% ferric chloride	5	24 (75)	...	0.7 (28)	...	254
Chemical lead	L51120	...	With 5% sulfuric acid	25	24 (75)	...	3.5 (140)	...	254
Chemical lead	L51120	...	With 5% sulfuric acid	25	66 (150)	...	4.0 (160)	...	254
Chemical lead	L51120	...	With 5% sulfuric acid	5	24 (75)	...	.35 (14)	...	254
Chemical lead	L51120	...	With 5% sulfuric acid	5	66 (150)	...	1.1 (42)	...	254
Chemical lead	L51120	...	With 7% sulfuric acid	3	24 (75)	...	.35 (14)	...	254
Chemical lead	L51120	...	With 7% sulfuric acid	3	66 (150)	...	.80 (32)	...	254
Chemical lead	L51120	...	With 9% sulfuric acid	1	24 (75)	...	.13 (5)	...	254
Chemical lead	L51120	...	With 9% sulfuric acid	1	66 (150)	...	.23 (9)	...	254
Gold	P00016	...	...	36	Room 100 (212)	...	0.05 (2) max	...	8
Iridium	...	...	...	36	100 (212)	...	Resistant	...	29
Lead	L50045	...	...	0-10	24 (75)	...	0.5 (1.25)	...	95
Lead	L50045	...	...	36	100 (212)	...	1.3 (51)	...	17
Lead	L50045	...	...	36	Room	...	0.25 (10) max	...	17
Lead	L50045	...	Specific gravity 1.6	...	100 (212)	...	2.5 (100)	...	17
Lead	L50045	...	Specific gravity 1.6	...	Room	...	Resistant	...	17
Lead, 6% anitmonial	L53110	...	With 1% sulfuric acid	9	24 (75)	...	0.8 (30)	...	254
Lead, 6% anitmonial	L53110	...	With 1% sulfuric acid	9	66 (150)	...	2.1 (84)	...	254
Lead, 6% anitmonial	L53110	...	With 10% sulfuric acid	20	24 (75)	...	2.8 (110)	...	254
Lead, 6% anitmonial	L53110	...	With 10% sulfuric acid	20	66 (150)	...	4.5 (180)	...	254
Lead, 6% anitmonial	L53110	...	With 15% sulfuric acid	15	24 (75)	...	2.3 (90)	...	254
Lead, 6% anitmonial	L53110	...	With 15% sulfuric acid	15	66 (150)	...	4.5 (180)	...	254
Lead, 6% anitmonial	L53110	...	With 20% sulfuric acid	10	24 (75)	...	2.0 (80)	...	254
Lead, 6% anitmonial	L53110	...	With 20% sulfuric acid	10	66 (150)	...	1.5 (58)	...	254
Lead, 6% anitmonial	L53110	...	With 25% sulfuric acid	5	24 (75)	...	0.6 (22)	...	254
Lead, 6% anitmonial	L53110	...	With 25% sulfuric acid	5	66 (150)	...	0.9 (34)	...	254
Lead, 6% anitmonial	L53110	...	With 3% sulfuric acid	7	24 (75)	...	0.6 (22)	...	255
Lead, 6% anitmonial	L53110	...	With 3% sulfuric acid	7	66 (150)	...	1.9 (74)	...	254
Lead, 6% anitmonial	L53110	...	With 5% sulfuric acid	5	24 (75)	...	.53 (21)	...	254
Lead, 6% anitmonial	L53110	...	With 5% sulfuric acid	5	66 (150)	...	1.6 (65)	...	254

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead, 6% anitmonial	L53110	...	With 5% sulfuric acid	25	24 (75)	...	3.8 (150)	...	254
Lead, 6% anitmonial	L53110	...	With 5% sulfuric acid	25	66 (150)	...	5.3 (210)	...	254
Lead, 6% anitmonial	L53110	...	With 7% sulfuric acid	3	24 (75)	...	.52 (21)	...	254
Lead, 6% anitmonial	L53110	...	With 7% sulfuric acid	3	66 (150)	...	1.0 (41)	...	254
Lead, 6% anitmonial	L53110	...	With 9% sulfuric acid	1	24 (75)	...	.13 (5)	...	254
Lead, 6% anitmonial	L53110	...	With 9% sulfuric acid	1	66 (150)	...	.30 (12)	...	254
Lead, 6% antimonial	L53110	...	...	1	24 (75)	...	0.8 (33)	...	131
Lead, 6% antimonial	L53110	...	...	1	24 (75)	...	0.8 (33)	...	254
Lead, 6% antimonial	L53110	...	...	10	24 (75)	...	1.1 (43)	...	131
Lead, 6% antimonial	L53110	...	...	10	24 (75)	...	1.1 (43)	...	254
Lead, 6% antimonial	L53110	...	...	15	24 (75)	...	3.8 (150)	...	135
Lead, 6% antimonial	L53110	...	...	15	24 (75)	...	3.8 (150)	...	254
Lead, 6% antimonial	L53110	...	...	20	24 (75)	...	4.0 (160)	...	254
Lead, 6% antimonial	L53110	...	...	25	24 (75)	...	5.0 (200)	...	254
Lead, 6% antimonial	L53110	...	...	35	24 (75)	...	14 (540)	...	254
Lead, 6% antimonial	L53110	...	...	5	24 (75)	...	0.5 (20)	...	131
Lead, 6% antimonial	L53110	...	...	5	24 (75)	...	0.5 (20)	...	254
Lead, 6% antimonial	L53110	...	With 25% sulfuric acid	25	66 (150)	...	5.3 (210)	...	254
Lead, 6% antimonial	L53110	...	With 30% sulfuric acid	20	66 (150)	...	3.3 (130)	...	254
Lead, 6% antimonial	L53110	...	With 35% sulfuric acid	15	66 (150)	...	3.0 (120)	...	254
Lead, 6% antimonial	L53110	...	With 40% sulfuric acid	10	66 (150)	...	2.1 (84)	...	254
Lead, 6% antimonial	L53110	...	With 45% sulfuric acid	5	66 (150)	...	1.3 (53)	...	254
Lead, 6% antimonial	L53110	...	With 5% ferric chloride	5	24 (75)	...	0.9 (37)	...	254
Lead, 6% antimonial	L53110	...	With 5% ferric chloride	10	24 (75)	...	1.9 (76)	...	254
Lead, 6% antimonial	L53110	...	With 5% ferric chloride	15	24 (75)	...	4.0 (160)	...	254
Lead, 6% antimonial	L53110	...	With 5% ferric chloride	20	24 (75)	...	4.8 (190)	...	254
Magnesium	...	...	...	All	Room	...	Poor	...	119
Osmium	...	...	...	36	100 (212)	...	0.25 (10) max	...	17
Osmium	...	...	...	36	Room	...	Resistant	...	17
Rhodium	P05990	...	...	35	100 (212)	...	Resistant	...	29
Ruthenium	...	...	...	36	100 (212)	...	Resistant	...	18
Silver	P07010	...	Limited aeration	15	20 (70)	...	0.007 (0.28)	...	135
Silver	P07010	...	Limited aeration	25	20 (70)	...	0.14 (5.5)	...	135
Silver	P07010	...	Limited aeration	36	20 (70)	...	0.07 (2.8)	...	135
Silver	P07010	...	Limited aeration	5	100 (212)	...	0.035 (1.4)	...	135
Silver	P07010	...	Strong aeration	15	20 (70)	...	0.085 (3.3)	...	135
Silver	P07010	...	Strong aeration	25	20 (70)	...	0.36 (14.2)	...	135
Silver	P07010	...	Strong aeration	36	100 (212)	...	2.5 (100)	...	135
Silver	P07010	...	Strong aeration	5	20 (70)	...	0.04 (1.6)	...	135
Tin	...	...	...	10	100 (212)	...	Poor	...	94
Tin	...	...	...	10	20 (68)	...	Poor	...	94
Tin	...	...	...	10	60 (140)	...	Poor	...	94
Tin	...	...	...	Concentrated	100 (212)	...	Poor	...	94
Tin	...	...	...	Concentrated	20 (68)	...	Poor	...	94
Tin	...	...	...	Concentrated	60 (140)	...	Poor	...	94
Tin	...	...	Hydrogen	6	...	...	0.3 (12)	...	59
Tin	...	...	Oxygen	6	...	...	55 (2200)	...	59
Nickel and alloys									
718	N07718	...	Acidizing fluid, with inhibitor	15	120	12 h	.005 (0.2)	...	207
Allcorr	N06110	Butt welded	...	10	104 (219)	...	22 (867)	Weld attack	220
Allcorr	N06110	Butt welded	...	10	55 (131)	...	0.71 (28.0)	Weld attack	220
Allcorr	N06110	Butt welded	...	15	108 (228)	...	15 (590)	Weld attack	220
Allcorr	N06110	Butt welded	...	35	84 (183)	...	7.9 (311)	Weld attack	220

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Allcorr	N06110	Butt welded	Plus 17% HNO_3	20	109 (228)	...	1.4 (55)	IGA	220
Alloy 625	N06625	...	...	1	Boiling	...	.025 (1)	...	212
Alloy 625	N06625	...	...	1.5	Boiling	...	8.8 (353)	...	225
Alloy 625	N06625	...	...	10	22 (72)	...	0.22 (8.9)	...	222
Alloy 625	N06625	...	...	10	66 (150)	...	3.60 (144)	...	222
Alloy 625	N06625	...	...	5	70 (158)	...	.85 (34)	...	222
Alloy 625	N06625	...	Plus 10% H_2SO_4	11	80 (176)	...	3.2 (179)	...	212
Alloy 625	N06625	...	Plus 25% HNO_3	11	80 (176)	...	3.2 (126)	...	212
Alloy 625	N06625	Butt welded	...	10	104 (219)	...	36 (1420)	...	220
Alloy 625	N06625	Butt welded	...	15	108 (228)	...	25 (985)	...	220
Alloy 625	N06625	Butt welded	...	15	55 (131)	...	0.84 (33)	...	220
Alloy 625	N06625	Butt welded	...	35	84 (183)	...	28 (1100)	...	220
Alloy 625	N06625	Butt welded	Plus 17% HNO_3	28	109 (228)	...	100 (3900) min	...	220
Alloy 825	N08825	...	...	1	Boiling	...	3.8 (150)	...	212
Alloy 825	N08825	...	Plus 10% H_2SO_4	11	80 (176)	...	7.4 (295)	...	212
Alloy 825	N08825	...	Plus 25% HNO_3	11	80 (176)	...	25 (1000)	...	212
Alloy C-22	N06022	...	...	1.5	Boiling	...	0.28 (11)	...	225
Alloy C-22	N06022	Butt welded	...	10	104 (219)	...	11 (433)	...	220
Alloy C-22	N06022	Butt welded	...	10	104 (219)	...	11	Weld attack	220
Alloy C-22	N06022	Butt welded	...	10	55 (131)	...	0.36	Weld attack	220
Alloy C-22	N06022	Butt welded	...	15	108 (228)	...	7.1 (280)	...	220
Alloy C-22	N06022	Butt welded	...	15	108 (228)	...	7.1	Weld attack	220
Alloy C-22	N06022	Butt welded	...	15	55 (131)	...	0.36 (14.2)	...	220
Alloy C-22	N06022	Butt welded	...	35	84 (183)	...	6.8	IGA	220
Alloy C-22	N06022	Butt welded	...	35	84 (193)	...	6.8 (268)	...	220
Alloy C-22	N06022	Butt welded	Plus 17% HNO_3	28	109 (228)	...	2.0 (79)	...	220
Alloy C-22	N06022	Butt welded	Plus 17% HNO_3	28	109 (228)	...	2.0	Weld attack	220
Alloy C-276	N10276	...	...	1.5	Boiling	...	0.72 (29)	...	225
Alloy C-276	N10276	...	...	10	75 (167)	...	1.0 (40)	...	222
Alloy C-276	N10276	Butt welded	...	10	104 (217)	...	6.1 (240)	Weld attack	220
Alloy C-276	N10276	Butt welded	...	15	108 (228)	...	5.6 (220)	IGA	220
Alloy C-276	N10276	Butt welded	...	15	55 (131)	...	0.28 (11.0)	...	220
Alloy C-276	N10276	Butt welded	...	35	84 (183)	...	4.1 (162)	IGA	220
Alloy C-276	N10276	Butt welded	Plus 17% HNO_3	28	109 (228)	...	17 (670)	Weld attack	220
Alloy C-4	N06455	...	...	1.5	Boiling	...	1.60 (64)	...	225
Alloy G-30	N06030	...	...	1	Boiling	...	.01 (0.4)	...	212
Alloy G-30	N06030	...	Plus 10% H_2SO_4	11	80 (176)	...	7.2 (285)	...	212
Alloy G-30	N06030	...	Plus 25% HNO_3	11	80 (176)	...	0.58 (23)	...	212
Cabot alloy No.625	N06625	...	...	2.5	70 (158)	100 h	0.02 (0.5) max	...	67
Cabot alloy No.625	N06625	...	...	2.5	Boiling	100 h	12 (472)	...	67
Cabot alloy No.625	N06625	...	...	2.5	Room	100 h	Resistant	...	67
Cabot alloy No.625	N06625	...	Average of four 24-h tests	5	70 (158)	...	0.86 (158)	...	67
Carpenter Pyromet Alloy 102	...	Annealed	...	10	...	48 h	8.6 (345)	...	30
Carpenter Pyromet Alloy 102	...	Annealed	...	Concentrated	...	48 h	11 (457)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	...	10	...	48 h	9.1 (366)	...	30
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	...	Concentrated	...	48 h	10 (406)	...	30
Cast Illium G	...	...	...	10	21 (70)	...	0.10 (4) min	...	126

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cast Illium G	...	...	...	16	50 (120)	...	3.12 (125) min	...	126
Cast Illium G	...	...	...	22	21 (70)	...	3.12 (125) max	...	126
Cast Illium G	...	...	...	22	50 (120)	...	3.12 (125) min	...	126
Cast Illium G	...	...	...	32	41 (105)	...	3.12 (125) min	...	126
Cast Illium G	...	...	...	5	21 (70)	...	0.10 (4) min	...	126
Cast Illium G	...	...	...	7	21 (70)	...	0.37 (15) max	...	126
Cast Illium G	...	...	...	7	50 (120)	...	3.12 (125) min	...	126
Cast Illium G	...	...	...	Concentrated	21 (70)	...	3.12 (125) min	...	126
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	1	Boiling	...	0.02 (0.8)	...	63
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	2	Boiling	...	0.08 (3)	...	63
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	5	Boiling	...	0.13 (5)	...	63
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	10	Boiling	...	0.18 (7)	...	63
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	15	Boiling	...	0.28 (11)	...	63
Hastelloy alloy B-2	N10665	All specimens were heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	20	Boiling	...	0.38 (15)	...	63
Hastelloy alloy B-2	N10665	As gas tungsten arc welded	Determined in lab tests	20	Boiling	...	0.51 (20)	...	63
Hastelloy alloy B-2	N10665	Sheet as solution heat-treated, 92 HRB	...	20	Boiling	...	0.36 (14)	...	63
Hastelloy alloy B-2	N10665	Sheet cold reduced 10%, 32 HRC	...	20	Boiling	...	0.36 (14)	...	63
Hastelloy alloy B-2	N10665	Sheet cold reduced 20%, 38 HRC	...	20	Boiling	...	0.36 (14)	...	63
Hastelloy alloy B-2	N10665	Sheet cold reduced 30%, 43 HRC	...	20	Boiling	...	0.33 (13)	...	63
Hastelloy alloy B-2	N10665	Sheet cold reduced 40%, 44 HRC	...	20	Boiling	...	0.36 (14)	...	63
Hastelloy alloy B-2	N10665	Sheet cold reduced 50%, 45 HRC	...	20	Boiling	...	0.36 (14)	...	63
Hastelloy alloy C-4	N06455	As gas tungsten arc welded	Determined in lab tests	10	75 (167)	...	0.86 (34)	...	16

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy alloy C-4	N06455	Heat-treated at 1066°C (1950°F), water quenched	Determined in lab tests	10	75 (167)	...	0.91 (36)	...	16
Hastelloy alloy C-4	N06455	Specimen aged 100 h at 899°C (1650°F)	Determined in lab tests	10	75 (167)	...	0.89 (35)	...	16
Hastelloy alloy G	N06007	Wrought	...	1	65 (150)	...	0.003 (0.1)	...	126
Hastelloy alloy G	N06007	Wrought	...	1	Room	...	0.003 (0.1)	...	126
Hastelloy alloy G	N06007	Wrought	...	10	65 (150)	...	3.6 (144)	...	126
Hastelloy alloy G	N06007	Wrought	...	10	Room	...	0.22 (8.9)	...	126
Hastelloy alloy G	N06007	Wrought	...	15	65 (150)	...	4.8 (192)	...	126
Hastelloy alloy G	N06007	Wrought	...	15	Room	...	0.25 (9.9)	...	126
Hastelloy alloy G	N06007	Wrought	...	2	Room	...	0.02 (0.8)	...	126
Hastelloy alloy G	N06007	Wrought	...	37	65 (150)	...	7.67 (307)	...	126
Hastelloy alloy G	N06007	Wrought	...	5	65 (150)	...	2.32 (93)	...	126
Hastelloy alloy G	N06007	Wrought	...	5	Room	...	0.09 (3.6)	...	126
Inco alloy C-276	N10276	As-welded with the gas-tungsten-arc method	Corrosion test ASTM G28	...	...	...	5.94 (234)	No grain separation on bending	40
Inco alloy C-276	N10276	Unwelded, solution heat treated specimens	Corrosion test ASTM G28	...	...	...	5.72 (225)	No grain separation on bending	40
Inco alloy G	N06007	...	...	10	66 (150)	...	144 (3.66)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	10	66 (150)	7 d	87 (2.2)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	10	66 (150)	7 d	92 (2.3)	...	40
Incoloy alloy 825	N08825	...	...	10	40 (104)	...	0.47 (18.6)	...	43
Incoloy alloy 825	N08825	...	...	10	66 (150)	...	2.6 (102.0)	...	43
Incoloy alloy 825	N08825	...	...	10	Room	...	0.18 (7)	...	64
Incoloy alloy 825	N08825	...	...	10	Room	...	0.18 (7.2)	...	43
Incoloy alloy 825	N08825	...	...	15	Room	...	0.18 (7)	...	64
Incoloy alloy 825	N08825	...	...	15	Room	...	0.19 (7.3)	...	43
Incoloy alloy 825	N08825	...	...	20	40 (104)	...	0.44 (17.2)	...	43
Incoloy alloy 825	N08825	...	...	20	66 (150)	...	1.52 (60.0)	...	43
Incoloy alloy 825	N08825	...	...	28	50 (120)	...	0.9 (36)	...	64
Incoloy alloy 825	N08825	...	...	5	40 (104)	...	0.45 (17.8)	...	43
Incoloy alloy 825	N08825	...	...	5	66 (150)	...	2.0 (79.0)	...	43
Incoloy alloy 825	N08825	...	...	5	Room	...	0.124 (4.9)	...	43
Incoloy alloy 825	N08825	...	...	5	Room	...	0.13 (5)	...	64
Incoloy alloy 825	N08825	...	...	Concentrated	40 (104)	...	12.2 (480)	...	43
Incoloy alloy 825	N08825	...	...	Concentrated	66 (150)	...	28.7 (1130)	...	43
Inconel 600	N06600	...	Air saturated, 16.5 ft/min	5	85 (185)	20 h	48.7 (1950)	...	133
Inconel 600	N06600	...	Air saturated, no velocity	5.9	30 (86)	120 h	1.12 (45)	...	133
Inconel 600	N06600	...	Air saturated, no velocity	5.9	80 (176)	120 h	17.8 (710)	...	133
Inconel 600	N06600	...	Air saturated, velocity 16.5 ft/min	5	30 (86)	20 h	2.4 (97)	...	133
Inconel 600	N06600	...	H_2 saturated, 16.5 ft/min	5	85 (185)	20 h	39.7 (1590)	...	133
Inconel 600	N06600	...	H_2 saturated, velocity 16.5 ft/min	5	30 (86)	20 h	0.32 (13)	...	133
Inconel 625	N06625	...	...	10	66 (150)	...	2.02 (81)	...	64
Inconel 625	N06625	...	...	10	66 (150)	...	2.1 (81)	...	64
Inconel 625	N06625	...	...	15	66 (150)	...	1.7 (65)	...	64
Inconel 625	N06625	...	...	15	66 (150)	...	1.92 (65)	...	64
Inconel 625	N06625	...	...	20	66 (150)	...	1.25 (50)	...	64
Inconel 625	N06625	...	...	20	66 (150)	...	16.5 (650)	...	64
Inconel 625	N06625	...	...	25	66 (150)	...	0.92 (38)	...	64

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 625	N06625	...	...	25	66 (150)	...	0.96 (38)	...	64
Inconel 625	N06625	...	...	30	66 (150)	...	0.82 (34)	...	64
Inconel 625	N06625	...	...	30	66 (150)	...	0.86 (34)	...	64
Inconel 625	N06625	...	...	37	66 (150)	...	0.38 (15)	...	64
Inconel 625	N06625	...	...	5	66 (150)	...	1.77 (71)	...	64
Inconel 625	N06625	...	...	5	66 (150)	...	1.8 (71)	...	64
Inconel 625	N06625	...	...	Concentrated	66 (150)	...	0.38 (15)	...	64
Monel 400	N04400	...	No velocity, no aeration	0.5	Boiling	10 d	0.73 (29)	...	134
Monel 400	N04400	...	No velocity, no aeration	1	Boiling	10 d	1.05 (42)	...	134
Monel 400	N04400	...	No velocity, no aeration	5	Boiling	10 d	1.1 (44)	...	134
Sanicro 28	N08028	...	...	1	Boiling	...	.025 (1)	...	212
Sanicro 28	N08028	...	Plus 10% H_2SO_4	11	80 (176)	...	18 (737)	...	212
Sanicro 28	N08028	...	Plus 25% HNO_3	11	80 (176)	...	25 (1015)	...	212
Refractory metals and alloys									
40Co-20Cr-15Ni-7Mo	...	...	...	10	102 (216)	50 h	72 (2870)	...	54
40Co-20Cr-15Ni-7Mo	...	...	...	50	110 (230)	50 h	55 (2200)	...	54
40Co-20Cr-15Ni-7Mo	...	...	...	Concentrated	110 (230)	50 h	48 (1900)	...	54
44Co-31Cr-13W	...	As cast. Cast specimens	Based on five 24-h test periods	5	Room	...	0.7 (26)	...	53
44Co-31Cr-13W	...	As cast. Cast specimens	Based on five 24-h test periods	5	Room	...	0.65 (26)	...	53
44Co-31Cr-13W	...	Heat treated 4h at 899°C (1650°F), furnace cooled. Cast specimens	Based on five 24-h test periods	5	Room	...	0.4 (16)	...	53
44Co-31Cr-13W	...	Heat treated 4h at 899°C (1650°F), furnace cooled. Cast specimens	Based on five 24-h test periods	5	Room	...	0.4 (16)	...	53
50Co-20Cr-15W-10Ni	...	...	...	5	Room	...	0.6 (24)	...	53
50Co-20Cr-15W-10Ni	...	Cast specimens	Based on five 24-h test periods	5	Room	...	0.6 (24)	...	53
53Co-30Cr-4.5W	...	As cast. Cast specimens	Based on five 24-h test periods	5	Room	...	1.3 (52)	...	53
53Co-30Cr-4.5W	...	As cast. Cast specimens	Based on five 24-h test periods	5	Room	...	1.3 (52)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast specimens	Based on five 24-h test periods	5	Room	...	0.225 (9)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F), furnace cooled. Cast specimens	Based on five 24-h test periods	5	Room	...	0.225 (9)	...	53
67Zr-33Ni	...	Amorphous	...	...	22-25	600 h	.003 (0.12)	...	204
67Zr-33Ni	...	Crystalline	...	...	22-25	600 h	.006 (0.24)	...	204
B/C-titanium	R58640	...	Acidizing fluid, with inhibitor	15	120	12 h	.35 (14.0)	...	207
Chromium + 0.5Pd	...	...	...	5	Boiling	50 h	0.2 (8) max	...	245
Chromium + 0.5Pt	...	...	...	5	Boiling	50 h	0.2 (8) max	...	245
Chromium	...	...	...	5	Boiling	50 h	58000 (2300000)	...	245
Co-20Cr	...	...	...	10	Boiling	...	250 (10,000)	...	35
Co-Cr-Ni	R31233	Diluted 16.7% with S31603	...	10	66	...	13 (520)	...	196
Co-Cr-Ni	R31233	Diluted 16.7% with S31603	...	3	66	...	2.1 (84)	...	196
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	10	66	...	11 (440)	...	196

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	3	66	...	1.4 (56)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with G10400	...	10	66	...	15 (600)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with G10400	...	3	66	...	1.8 (72)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with S31603	...	10	66	...	20 (800)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with S31603	...	3	66	...	2.1 (84)	...	196
Co-Cr-Ni	R31233	Welding rod	...	10	66	...	7.5 (300)	...	196
Co-Cr-Ni	R31233	Welding rod	...	3	66	...	0.68 (27)	...	196
Hafnium	...	...	...	20	...	8 d	0.005 (0.2)	...	11
Hafnium	...	...	...	20	...	8 d	0.005 (0.2)	...	11
Haynes alloy 6B	...	...	...	5	Boiling	24 h	250 (10000) min	...	23
Haynes alloy 6B	...	...	Average of four 24-h test periods	2.5	Boiling	...	97 (3800)	...	23
Haynes alloy No.188	R30188	...	...	5	Boiling	24 h	140 (5500)	...	23
Haynes alloy No.188	R30188	...	Average of four 24-h test periods	2.5	Boiling	...	61 (2400)	...	23
Haynes alloy No.188	R30188	...	Average of four 24-h test periods. Corrosion decreased from a high value	1	Boiling	...	Resistant	...	23
Haynes alloy No.188	R30188	...	Average of four 24-h test periods. Corrosion rate oscillated during test period	10	Room	...	0.8 (31) max	...	23
Haynes alloy No.25	R30605	...	...	5	Boiling	24 h	188 (7400)	...	23
Haynes alloy No.25	R30605	...	Average of four 24-h test periods	1	Boiling	...	0.56 (22)	...	23
Haynes alloy No.25	R30605	...	Average of four 24-h test periods	2.5	Boiling	...	57 (2260)	...	23
Haynes alloy No.25	R30605	...	Average of four 24-h test periods	10	Room	...	Resistant	...	23
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	Room	24 h	0.01 (0.1) max	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	66 (150)	24 h	Resistant	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	Boiling	24 h	10.2 (400)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	Room	24 h	0.01 (0.1) max	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	66 (150)	24 h	0.01 (0.1)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	Boiling	24 h	25.4 (1000) min	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	Room	24 h	0.61 (24)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	66 (150)	24 h	12.0 (474)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	Boiling	24 h	25.4 (1000) min	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	Room	24 h	0.64 (25)	...	124

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	66 (150)	24 h	10.7 (420)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	Boiling	24 h	25.4 (1000) min	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	Room	24 h	0.74 (29)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	66 (150)	24 h	14.0 (552)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	Boiling	24 h	25.4 (1000) min	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	Room	24 h	0.15 (6.0)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	66 (150)	24 h	6.81 (268)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	Boiling	24 h	25.4 (1000) min	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	25	Room	24 h	0.10 (4.0)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	25	66 (150)	24 h	3.7 (144)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	37	Room	24 h	0.05 (2.0)	...	124
Haynes alloy No.25	R30605	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	37	66 (150)	24 h	1.73 (68)	...	124
Haynes alloy No.556	R30556	...	...	5	Boiling	24 h	165 (6600)	...	23
Haynes alloy No.556	R30556	...	Average of four 24-h test periods	2.5	Boiling	...	63.5 (2500)	...	23
Haynes alloy No.556	R30556	...	Average of four 24-h test periods	10	Room	...	0.6 (23)	...	23
Haynes alloy No.556	R30556	...	Average of four 24-h test periods. Corrosion rate decreased from a high value	1	Boiling	...	Resistant	...	23
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	Room	24 h	0.01 (0.1) max	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	66 (150)	24 h	Resistant	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	1	Boiling	24 h	9.40 (370)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	Room	24 h	0.01 (0.1) max	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	66 (150)	24 h	Resistant	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	2	Boiling	24 h	22.7 (934)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	Room	24 h	0.43 (17)	...	124

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	66 (150)	24 h	8.71 (343)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	5	Boiling	24 h	25.4 (1000) min	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	Room	24 h	0.33 (13)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	66 (150)	24 h	14.5 (572)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	10	Boiling	24 h	25.4 (1000) min	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	Room	24 h	0.38 (15)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	66 (150)	24 h	10.9 (431)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	15	Boiling	24 h	25.4 (1000) min	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	Room	24 h	0.20 (8.0)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	66 (150)	24 h	10.8 (424)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	20	Boiling	24 h	25.4 (1000) min	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	25	Room	24 h	0.15 (6.0)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	25	66 (150)	24 h	17.4 (687)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	37	Room	24 h	0.28 (11)	...	124
Multimet	R30155	12-gage, solution heat-treated sheet	Calculated on a minimum of five 24-h test periods	37	66 (150)	24 h	25.4 (1000) min	...	124
Niobium alloy	...	Arc melted	Wrought 50% V, 50% Cb. Average of three 48-h periods	15	Boiling	48 h	2.07 (83)	...	33
Niobium alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 0.75% Zr, bal Cb. Average of three 48-h periods	15	Boiling	48 h	0.25 (10)	Embrittled	33
Niobium alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 0.75% Zr, bal Nb. Average of three 48-h periods	20	Boiling	48 h	0.52 (21)	Embrittled	33
Niobium alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 6.9% Ti, 0.81% Zr, bal Cb. Average of three 48-h periods	20	Boiling	48 h	0.775 (31)	Embrittled	33
Niobium alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 8% Ti, bal Cb. Average of three 48-h periods	15	Boiling	48 h	0.32 (13)	...	33
Niobium alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 8% Ti, bal Cb. Average of three 48-h periods	20	Boiling	48 h	0.7 (28)	...	33

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium alloy	...	Arc melted; annealed at 1430°C (2606°F) for 1 h	Wrought 6.9% Ti, 0.81% Zr, bal Cb. Average of three 48-h periods	15	Boiling	48 h	0.27 (11)	...	33
Niobium	R04210	...	...	1	190 (375)	...	0.02 (1) max	...	37
Niobium	R04210	...	...	1	Boiling	...	0.02 (1) max	...	37
Niobium	R04210	...	...	1	Boiling	...	Resistant	...	2
Niobium	R04210	...	...	10	Boiling	...	0.12 (5) max	...	37
Niobium	R04210	...	...	15	190 (375)	...	12 (500) min	...	37
Niobium	R04210	...	...	15	Boiling	...	6.35 (25) max	...	37
Niobium	R04210	...	...	18	19-26 (65-80)	36 d	Resistant	...	74
Niobium	R04210	...	...	20	Boiling	...	1.2 (50) max	...	37
Niobium	R04210	...	...	37	110 (230)	7 d	0.1 (4)	Tarnished	74
Niobium	R04210	...	...	37	19-26 (65-80)	36 d	0.05 (0.12)	...	74
Niobium	R04210	...	...	37	60 (140)	...	0.25 (10)	...	2
Niobium	R04210	...	...	37	Room	...	0.025 (1.0)	...	2
Niobium	R04210	...	...	5	190 (375)	...	0.02 (1) max	...	37
Niobium	R04210	...	...	5	Boiling	...	0.05 (2) max	...	37
Niobium	R04210	...	Aerated	15	100 (212)	...	0.025 (1.0)	...	2
Niobium	R04210	...	Aerated	15	Room-60 (140)	...	Resistant	...	2
Niobium	R04210	...	Aerated	30	100 (212)	...	0.125 (5.0)	...	2
Niobium	R04210	...	Aerated	30	35 (95)	...	0.025 (1.0)	...	2
Niobium	R04210	...	Aerated	30	60 (140)	...	0.05 (2.0)	...	2
Niobium	R04210	...	Plus 0.1% $FeCl_3$	10	Boiling	...	0.025 (1.0)	...	2
Niobium	R04210	...	Plus 0.6% $FeCl_3$	10	Boiling	...	0.125 (5.0)	...	2
Niobium	R04210	...	Plus 35% $FeCl_2$ and 2% $FeCl_3$	10	Boiling	...	0.05 (2.0)	...	2
Niobium	R04210	...	Plus Cl_2	37	60 (140)	...	0.5 (20)	...	2
Niobium	R04210	Wrought; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	15	Boiling	48 h	0.22 (9)	Embrittled	33
Niobium	R04210	Wrought; arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	20	Boiling	48 h	0.6 (24)	Embrittled	33
Niobium	R04210	Wrought; electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	15	Boiling	48 h	0.22 (9)	Embrittled	33
Niobium	R04210	Wrought; electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	20	Boiling	48 h	0.52 (21)	Embrittled	33
Niobium	R04210	Wrought; lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h periods	15	Boiling	48 h	0.45 (18)	Embrittled	33
Niobium	R04210	Wrought; lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h periods	20	Boiling	48 h	0.95 (38)	Embrittled	33
Pure Titanium	...	...	...	10	Boiling	24 h	1.7 (67)	...	245

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Pure Titanium	...	...	...	10	Boiling	24 h	114 (4450)	...	245
Pure Titanium	...	...	...	3	Boiling	24 h	0.05 (2) max	...	245
Pure Titanium	...	...	...	3	Boiling	24 h	6.1 (240)	...	245
Ta-Mo alloy (0 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.005 (0.2)	...	56
Ta-Mo alloy (10.1 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.005 (0.2)	...	56
Ta-Mo alloy (20.1 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.005 (0.2)	...	56
Ta-Mo alloy (30.0 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy (40.0 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy (50.0 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy (61.2 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1) max	...	56
Ta-Mo alloy (82.8 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1) max	...	56
Ta-Mo alloy (91.4 % Ta)	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1) max	...	56
Tantalum	...	...	Solutions saturated with oxygen	Concentrated	55 (131)	...	0.003 (0.1) max	...	56
Tantalum	R05210	...	...	1	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	1	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	15	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	15	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	18	19-26 (65-80)	36 d	Resistant	...	74
Tantalum	R05210	...	...	20	100 (212)	...	Resistant	...	42
Tantalum	R05210	...	...	20	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	20	21 (70)	...	Resistant	...	42
Tantalum	R05210	...	...	20	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	25	190 (375)	...	0.05 (2) max	...	37
Tantalum	R05210	...	...	30	190 (375)	...	0.15 (6) max	...	37
Tantalum	R05210	...	...	37	110 (230)	7 d	Resistant	...	74
Tantalum	R05210	...	...	37	19-26 (65-80)	36 d	Resistant	...	74
Tantalum	R05210	...	...	5	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	5	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	Concentrated	100 (212)	...	Resistant	...	42
Tantalum	R05210	...	...	Concentrated	21 (70)	...	Resistant	...	42
Tantalum	R05210	...	Average of 29 tests. of 90-h duration on 8 lots of tantalum	Concentrated	190 (375)	...	0.07 (30) max	...	37
Tantalum	R05210	...	High purity. Average of three 48-h periods	15	Boiling	48 h	0.025 (1) max	...	33
Tantalum	R05210	...	High purity. Average of three 48-h periods	20	Boiling	48 h	0.025 (1) max	...	33
Tantalum	R05210	Commercial sheet	Average of three 48-h periods	15	Boiling	48 h	0.025 (1) max	...	33
Tantalum	R05210	Commercial sheet	Average of three 48-h periods	20	Boiling	48 h	0.025 (1) max	...	33
Ti-10-2-3	...	...	...	0.5	Boiling	...	1.10 (44)	...	33
Ti-10-2-3	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.008 (0.32)	...	33
Ti-3-8-6-4-4	R58640	...	...	0.5	Boiling	...	0.003 (0.12)	...	33
Ti-3-8-6-4-4	R58640	...	...	1.0	Boiling	...	0.058 (2.3)	...	33
Ti-3-8-6-4-4	R58640	...	...	1.5	Boiling	...	0.26 (10.4)	...	33
Ti-3-8-6-4-4	R58640	...	Aerated. pH 1	...	Boiling	...	Resistant	...	33

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ti-3-8-6-4-4	R58640	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.018 (0.70)	...	33
Ti-3Al-2.5V	...	...	...	1	Boiling	...	2.75 (110)	...	91
Ti-3Al-2.5V	...	...	...	10	Boiling	...	75 (3000) min	...	91
Ti-3Al-2.5V	...	...	...	5	Boiling	...	26.3 (1055)	...	91
Ti-3Al-2.5V	...	...	Plus 0.2% $FeCl_3$	1	Boiling	...	0.005 (0.2)	...	91
Ti-3Al-2.5V	...	...	Plus 0.2% $FeCl_3$	10	Boiling	...	0.3 (12)	...	91
Ti-3Al-2.5V	...	...	Plus 0.2% $FeCl_3$	5	Boiling	...	0.03 (1.3)	...	91
Ti-550	...	...	...	0.5	Boiling	...	0.056 (2.24)	...	33
Ti-550	...	...	...	1.0	Boiling	...	0.64 (25.6)	...	33
Ti-550	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.393 (15.4)	...	33
Ti-5Ta	...	...	...	0.5	Boiling	...	0.013 (0.52)	...	33
Ti-5Ta	...	...	...	1.5	Boiling	...	2.10 (84)	...	33
Ti-5Ta	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.020 (0.78)	...	33
Ti-6-2-1-0.8	...	...	...	0.5	Boiling	...	0.020 (0.8)	...	33
Ti-6-2-1-0.8	...	...	...	1.0	Boiling	...	1.07 (42.8)	...	33
Ti-6-2-1-0.8	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.051 (2.00)	...	33
Ti-6-2-4-6	R56260	...	...	0.5	Boiling	...	Resistant	...	33
Ti-6-2-4-6	R56260	...	...	1.0	Boiling	...	0.03 (1.2)	...	33
Ti-6-2-4-6	R56260	...	Aerated. pH 1	...	Boiling	...	0.01 (0.4)	...	33
Ti-6-2-4-6	R56260	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.068 (2.67)	...	33
Ti-6-4, grade 5	R56400	...	...	1.0	Boiling	...	2.52 (100)	...	33
Ti-6-4, grade 5	R56400	...	Aerated. pH 1	...	Boiling	...	0.60 (24)	...	33
Ti-6-4, grade 5	R56400	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.015 (0.59)	...	33
Titanium + 0.4Pd	...	...	...	10	Boiling	24 h	3.0 (118)	...	245
Titanium + 0.54Pd	...	...	...	3	Boiling	24 h	.07 (2.8)	...	245
Titanium	...	...	...	0.1	Boiling	...	0.10 (4)	...	90
Titanium	...	...	...	1	Boiling	...	1.8 (72)	...	90
Titanium	...	...	...	1	Boiling	...	2.12 (85)	...	91
Titanium	...	...	...	10	Boiling	...	50 (2000) min	...	91
Titanium	...	...	...	18	19-26 (65-80)	36 d	0.11 (4.5)	...	74
Titanium	...	...	...	37	19-26 (65-80)	36 d	17.7 (698)	...	74
Titanium	...	...	...	5	Boiling	...	21 (840)	...	91
Titanium	...	...	Aerated	1	100 (212)	...	0.46 (18.4)	...	90
Titanium	...	...	Aerated	1	60 (140)	...	0.004 (0.16)	...	90
Titanium	...	...	Aerated	10	35 (95)	...	1.02 (40.8)	...	90
Titanium	...	...	Aerated	2	60 (140)	...	0.016 (0.64)	...	90
Titanium	...	...	Aerated	20	35 (95)	...	4.45 (178)	...	90
Titanium	...	...	Aerated	5	35 (95)	...	0.01 (0.4)	...	90
Titanium	...	...	Aerated	5	60 (140)	...	1.07 (42.8)	...	90
Titanium	...	...	Chlorine saturated	10	190 (374)	...	28.5 (1140)	...	90
Titanium	...	...	Chlorine saturated	5	190 (374)	...	0.025 (1) max	...	90
Titanium	...	...	Plus 0.05% $CuSO_4$	5	38 (100)	...	0.040 (1.6)	...	90
Titanium	...	...	Plus 0.05% $CuSO_4$	5	38 (100)	...	0.091 (3.64)	...	90
Titanium	...	...	Plus 0.05% $CuSO_4$	5	93 (200)	...	0.091 (3.64)	...	90
Titanium	...	...	Plus 0.05% $CuSO_4$	5	Boiling	...	0.064 (2.56)	...	90
Titanium	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.01 (0.4)	...	90
Titanium	...	...	Plus 0.2% $FeCl_3$	1	Boiling	...	0.125 (5) max	...	91
Titanium	...	...	Plus 0.2% $FeCl_3$	10	Boiling	...	0.125 (5) max	...	91
Titanium	...	...	Plus 0.2% $FeCl_3$	5	Boiling	...	0.125 (5) max	...	91
Titanium	...	...	Plus 0.5% CrO_3	5	38 (100)	...	Resistant	...	90
Titanium	...	...	Plus 0.5% CrO_3	5	95 (203)	...	0.031 (1.24)	...	90
Titanium	...	...	Plus 0.5% $CuSO_4$	5	93 (200)	...	0.061 (2.44)	...	90
Titanium	...	...	Plus 0.5% $CuSO_4$	5	Boiling	...	0.084 (3.36)	...	90
Titanium	...	...	Plus 1 g/L Ti^{4+}	10	Boiling	...	0.000 (0.000)	...	90

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	Plus 1% CrO_3	5	38 (100)	...	0.018 (0.72)	...	90
Titanium	...	...	Plus 1% CrO_3	5	95 (203)	...	0.031 (1.24)	...	90
Titanium	...	...	Plus 1% $CuSO_4$	5	38 (100)	...	0.031 (1.24)	...	90
Titanium	...	...	Plus 1% $CuSO_4$	5	93 (200)	...	0.091 (3.64)	...	90
Titanium	...	...	Plus 1% HNO_3	5	40 (104)	...	Resistant	...	90
Titanium	...	...	Plus 1% HNO_3	5	95 (203)	...	0.091 (3.64)	...	90
Titanium	...	...	Plus 10% HNO_3	5	40 (104)	...	Resistant	...	90
Titanium	...	...	Plus 10% HNO_3	5	95 (203)	...	0.183 (7.32)	...	90
Titanium	...	...	Plus 18% H_3PO_4 + 5% HNO_3	18	77 (171)	...	0.000 (0.000)	...	90
Titanium	...	...	Plus 2.5% $NaClO_3$	10.2	80 (176)	...	0.009 (0.36)	...	90
Titanium	...	...	Plus 200 ppm Cl_2	36	25 (77)	...	0.432 (17.28)	...	90
Titanium	...	...	Plus 3% HNO_3	8.5	80 (176)	...	0.051 (2.04)	...	90
Titanium	...	...	Plus 4% $FeCl_3$ + 4% $MgCl_2$ + Cl_2 saturated	19	82 (180)	...	0.46 (18.4)	...	90
Titanium	...	...	Plus 4% $FeCl_3$ + 4% $MgCl_2$	19	82 (180)	...	0.51 (20.4)	...	90
Titanium	...	...	Plus 5% $CuSO_4$	5	38 (100)	...	0.020 (0.8)	...	90
Titanium	...	...	Plus 5% $CuSO_4$	5	93 (200)	...	0.061 (2.44)	...	90
Titanium	...	...	Plus 5% HNO_3	1	Boiling	...	0.074 (2.96)	...	90
Titanium	...	...	Plus 5% HNO_3	5	40 (104)	...	0.025 (1)	...	90
Titanium	...	...	Plus 5% HNO_3	5	95 (203)	...	0.030 (1.2)	...	90
Titanium	...	...	Plus 5.0% $NaClO_3$	10.2	80 (176)	...	0.006 (0.24)	...	90
Titanium	...	...	Plus 5.8 g/L Ti^{4+}	20	Boiling	...	0.000 (0.000)	...	90
Titanium, grade 12	R53400	...	...	0.5	Boiling	...	Resistant	...	33
Titanium, grade 12	R53400	...	...	1.0	Boiling	...	0.04 (1.6)	...	33
Titanium, grade 12	R53400	...	...	1.5	Boiling	...	0.25 (10)	...	33
Titanium, grade 12	R53400	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.020 (0.78)	...	33
Titanium, grade 12	R53400	...	Plus 2 g/L $FeCl_3$	4.2	91 (195)	...	0.058 (2.28)	...	33
Titanium, grade 7	R52400	...	...	0.5	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	...	1.0	Boiling	...	0.008 (0.32)	...	33
Titanium, grade 7	R52400	...	...	1.5	Boiling	...	0.03 (1.2)	...	33
Titanium, grade 7	R52400	...	...	5.0	Boiling	...	0.23 (9.2)	...	33
Titanium, grade 7	R52400	...	Aerated	1	70 (158)	...	0.03 (1.18) max	...	33
Titanium, grade 7	R52400	...	Aerated	10	70 (158)	...	0.05 (1.96)	...	33
Titanium, grade 7	R52400	...	Aerated	15	70 (158)	...	0.15 (5.9)	...	33
Titanium, grade 7	R52400	...	Aerated	5	70 (158)	...	0.03 (1.18) max	...	33
Titanium, grade 7	R52400	...	Chlorine saturated	10	190 (375)	...	29.0 (1141)	...	33
Titanium, grade 7	R52400	...	Chlorine saturated	3	190 (375)	...	0.03 (1.18) max	...	33
Titanium, grade 7	R52400	...	Chlorine saturated	5	190 (375)	...	0.03 (1.18) max	...	33
Titanium, grade 7	R52400	...	Deaerated	10	82 (180)	...	0.419 (16.7)	...	33
Titanium, grade 7	R52400	...	Deaerated	3	82 (180)	...	0.013 (0.52)	...	33
Titanium, grade 7	R52400	...	Deaerated	5	82 (180)	...	0.051 (2.04)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	1-15	25 (75)	...	0.025 (1) max	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	10	70 (158)	...	0.178 (7.12)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	10	190 (375)	...	8.9 (356)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	15	70 (158)	...	0.33 (13.2)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	20	25 (75)	...	0.102 (4.08)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	3	190 (375)	...	0.025 (0.63)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	5	70 (158)	...	0.076 (3.04)	...	33
Titanium, grade 7	R52400	...	Hydrogen saturated	5	190 (375)	...	0.025 (1)	...	33
Titanium, grade 7	R52400	...	Oxygen saturated	10	190 (375)	...	9.3 (366)	...	33
Titanium, grade 7	R52400	...	Oxygen saturated	3	190 (375)	...	0.127 (5.0)	...	33
Titanium, grade 7	R52400	...	Oxygen saturated	5	190 (375)	...	0.127 (5.0)	...	33
Titanium, grade 7	R52400	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.013 (0.51)	...	33

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Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium, grade 7	R52400	...	Plus 16 g/L $CuCl_2$	10	Boiling	...	0.127 (5.0)	...	33
Titanium, grade 7	R52400	...	Plus 16 g/L $FeCl_3$	10	Boiling	...	0.076 (2.99)	...	33
Titanium, grade 7	R52400	...	Plus 18% H_3PO_4, 5% HNO_3	18	77 (170)	...	Resistant	...	33
Titanium, grade 7	R52400	...	Plus 4% $FeCl_3$, 4% $MgCl_2$	19	82 (180)	...	0.49 (19.2)	...	33
Titanium, grade 7	R52400	...	Plus 4% $FeCl_3$, 4% $MgCl_2$. Chlorine saturated	19	82 (180)	...	0.46 (18.1)	...	33
Titanium, grade 7	R52400	...	Plus 5 g/L $FeCl_3$	10	Boiling	...	0.279 (10.9)	...	33
Titanium, grade 9	...	...	...	0.5	Boiling	...	1.08 (43.2)	...	33
Titanium, grade 9	...	...	...	1	88 (190)	...	0.009 (0.36)	...	33
Titanium, grade 9	...	...	...	1	Boiling	...	2.8 (110)	...	33
Titanium, grade 9	...	...	...	3	88 (190)	...	3.10 (124)	...	33
Titanium, grade 9	...	...	Aerated	5	35 (95)	...	0.001 (0.04)	...	33
Titanium, grade 9	...	...	Nitrogen saturated	5	35 (95)	...	0.185 (7.4)	...	33
Titanium, grade 9	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.008 (0.31)	...	33
Titanium, grade 9	...	...	Plus 0.2% $FeCl_3$	1	Boiling	...	0.005 (0.19)	...	33
Titanium, grade 9	...	...	Plus 0.2% $FeCl_3$	10	Boiling	...	0.305 (12.0)	...	33
Titanium, grade 9	...	...	Plus 0.2% $FeCl_3$	5	Boiling	...	0.033 (1.29)	...	33
Transage 207	...	...	...	0.5	Boiling	...	0.005 (0.2)	...	33
Transage 207	...	...	...	1.0	Boiling	...	0.025 (1)	...	33
Transage 207	...	...	Plus 0.1% $FeCl_3$	5	Boiling	...	0.048 (1.88)	...	33
Zirconium	R60701	...	...	37	110 (230)	7 d	0.48 (18.75)	...	74
Zirconium	R60701	...	...	37	19-26 (65-80)	36 d	0.002 (0.08)	...	74
Zirconium	R60701	...	Became brittle	18	19-26 (65-80)	36 d	0.06 (0.09)	...	74
Zirconium	R60701	...	Plus 10% HNO_3	10	Room	...	Poor	...	36
Zirconium	R60701	...	Plus 20% HNO_3	20	Room	...	Poor	...	36
Zr702	R60702	...	...	10	35 (95)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	2	225 (435)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	20	35 (95)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	32	30 (85)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	32	82 (180)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	5	Room	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 100 ppm $FeCl_3$	10	105 (220)	...	0.13 (5) max	Pitting	15
Zr702	R60702	...	Plus 100 ppm $FeCl^3$	10	30 (85)	...	0.025 (1) max	Stress-corrosion cracking	15
Zr702	R60702	...	Plus 100 ppm $FeCl_3$	20	105 (220)	...	0.13 (5) max	...	15
Zr702	R60702	...	Plus 100 ppm $FeCl_3$	37	53 (125)	...	0.25 (10) max	Stress-corrosion cracking	15
Zr702	R60702	...	Plus 20% HNO_3	10	Room	...	Poor	...	15
Zr702	R60702	...	Plus 20% HNO_3	20	Room	...	Poor	...	15
Zr702	R60702	...	Plus Cl_2 gas	20	58 (135)	...	0.25 (10) max	Pitting	15
Zr702	R60702	...	Plus Cl_2 gas	37	58 (135)	...	0.13 (5) max	...	15
Zr704	R60704	...	Plus 100 ppm $FeCl_3$	10	30 (85)	...	0.05 (2) max	Stress-corrosion cracking	15
Zr705	R60705	...	...	2	225 (435)	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 100 ppm $FeCl_3$	10	30 (85)	...	0.025 (1) max	Stress-corrosion cracking	15
Stainless steels									
13Cr steel	S41000	...	Acidizing fluid, with inhibitor	15	120	12 h	1.47 (58.7)	...	207
20 Cb-3	N08020	...	...	1	Boiling	...	2.30 (92)	...	212
20 Cb-3	N08020	...	Plus 10% H_2SO_4	11	80 (176)	...	9.3 (373)	...	212
20 Cb-3	N08020	...	Plus 25% HNO_3	11	80 (176)	...	25 (1000)	...	212
301	S30100	...	...	0.5	20 (68)	...	Good	Pitting	253
301	S30100	...	...	0.5	Boiling	...	Poor	Pitting	253
302	S30200	...	...	0.5	20 (68)	...	Good	Pitting	253

(Continued)

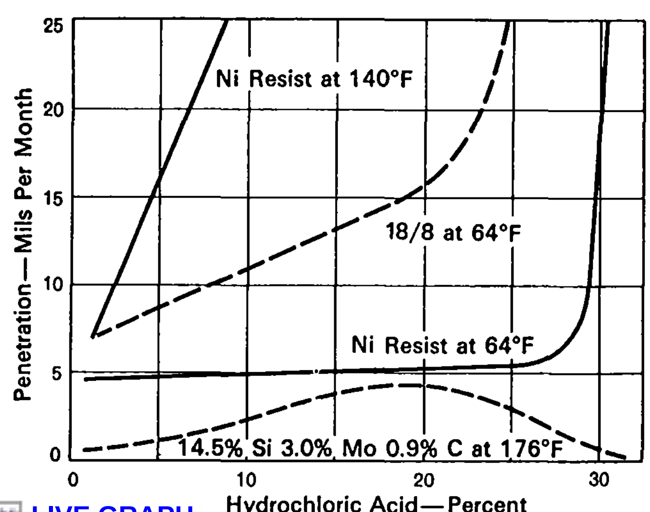
Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	0.5	Boiling	...	Poor	Pitting	253
303	S30300	...	...	0.5	20 (68)	...	Good	Pitting	253
303	S30300	...	...	0.5	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	0.5	Boiling	...	Poor	Pitting	253
303	S30300	...	...	0.5	Boiling	...	Poor	Pitting	253
304	S30400	...	...	0.5	20 (68)	...	Good	Pitting	253
304	S30400	...	...	0.5	Boiling	...	Poor	Pitting	253
304	S30400	...	...	All	21 (70)	...	Poor	...	121
304	S30400	Annealed	All solutions from CP chemicals. Tests made in the lab	0.4	27 (80)	...	0.250 (10)	...	19
304L	S30403	...	...	0.5	20 (68)	...	Good	Pitting	253
304L	S30403	...	...	0.5	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	0.5	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	0.5	Boiling	...	Poor	Pitting	253
316	S31600	...	...	0.5	20 (68)	...	Good	Pitting	253
316	S31600	...	...	0.5	Boiling	...	Poor	Pitting	253
316	S31600	...	...	All	21 (70)	...	Poor	...	121
316	S31600	Annealed	All solutions from CP chemicals. Tests made in the lab	0.4	49 (120)	...	0.125 (5)	...	19
316F	S31620	...	...	0.5	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	0.5	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	0.5	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	0.5	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	1	Boiling	...	12.3 (490)	...	212
316L	S31603	...	Plus 10% H_2SO_4	11	80 (176)	...	250 (10000)	...	212
316L	S31603	...	Plus 25% HNO_3	11	80 (176)	...	250 (10000)	...	212
316LN	S31653	...	...	0.5	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	0.5	Boiling	...	Poor	Pitting	253
316Ti	S31635	...	...	0.5	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	0.5	Boiling	...	Poor	Pitting	253
317L	S31703	...	...	0.5	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	0.5	Boiling	...	Poor	Pitting	253
317L	S31703	...	...	1	Boiling	...	.003 (0.1)	...	219
317L	S31703	...	...	5	Boiling	48 h	37 (1.5)	...	97
317L	S31703	...	...	5	Boiling	48 h	43 (1.7)	...	97
317LN	S31725	...	...	0.5	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	0.5	Boiling	...	Poor	Pitting	253
321	S32100	...	...	0.5	20 (68)	...	Good	Pitting	253
321	S32100	...	...	0.5	Boiling	...	Poor	Pitting	253
329	S32900	...	...	0.5	20 (68)	...	Good	Pitting	253
329	S32900	...	...	0.5	Boiling	...	Poor	Pitting	253
347	S34700	...	...	0.5	20 (68)	...	Good	Pitting	253
347	S34700	...	...	0.5	Boiling	...	Poor	Pitting	253
403	S40300	...	...	0.5	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	0.5	Boiling	...	Poor	Pitting	253
405	S40500	...	...	0.5	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	0.5	Boiling	...	Poor	Pitting	253
409	S40900	...	...	0.5	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	0.5	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	0.5	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	0.5	Boiling	...	Poor	Pitting	253
410	S41000	...	...	All	21 (70)	...	Poor	...	121

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrochloric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	...	0.5	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	0.5	Boiling	...	Poor	Pitting	253
420	S42000	...	...	0.5	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	0.5	Boiling	...	Poor	Pitting	253
430	S43000	...	...	0.5	20 (68)	...	Questionable	Pitting	253
430	S43000	...	...	0.5	Boiling	...	Poor	Pitting	253
430	S43000	...	...	All	21 (70)	...	Poor	...	121
434	S43400	...	...	0.5	20 (68)	...	Questionable	Pitting	253
434	S43400	...	...	0.5	Boiling	...	Poor	Pitting	253
AL 2205	S31803	...	...	1	Boiling	...	.003 (0.1)	...	219
AL 2205	S31803	...	Acidizing fluid, with inhibitor	15	120	12 h	2.45 (97.8)	...	207
AL 904L	N08904	...	...	1	Boiling	...	7.3 (292)	...	212
AL 904L	N08904	...	Plus 10% H_2SO_4	11	80 (176)	...	13 (520)	...	212
AL 904L	N08904	...	Plus 25% HNO_3	11	80 (176)	...	157 (6281)	...	212
AM-363	S36300	...	...	...	Room	...	Poor	...	120
F51	S31803	...	...	0.5	20 (68)	...	Good	Pitting	253
F51	S31803	...	...	0.5	Boiling	...	Poor	Pitting	253
Fe-47Cr (ferrite)	...	...	Reducing	10	Boiling	...	690 (275,000)	...	58
Fe-47Cr (sigma)	...	...	Reducing	10	Boiling	...	35,000 (1,410,000)	...	58
Ferralium 255	S32250	...	...	1	Boiling	...	.003 (0.1)	...	219
Jessop JS700	N08700	...	...	10	60 (140)	48 h	3.8 (150)	...	97
Jessop JS700	N08700	...	...	10	Boiling	48 h	110 (4500)	...	97
Jessop JS700	N08700	...	...	10	Room	48 h	0.46 (18)	...	97
Jessop JS700	N08700	...	...	5	Boiling	48 h	38 (1490)	...	97
Jessop JS700	N08700	...	1 volume concentrated HCl in 9 volumes ethylene diamine	10	Boiling	48 h	0.025 (1) max	...	97



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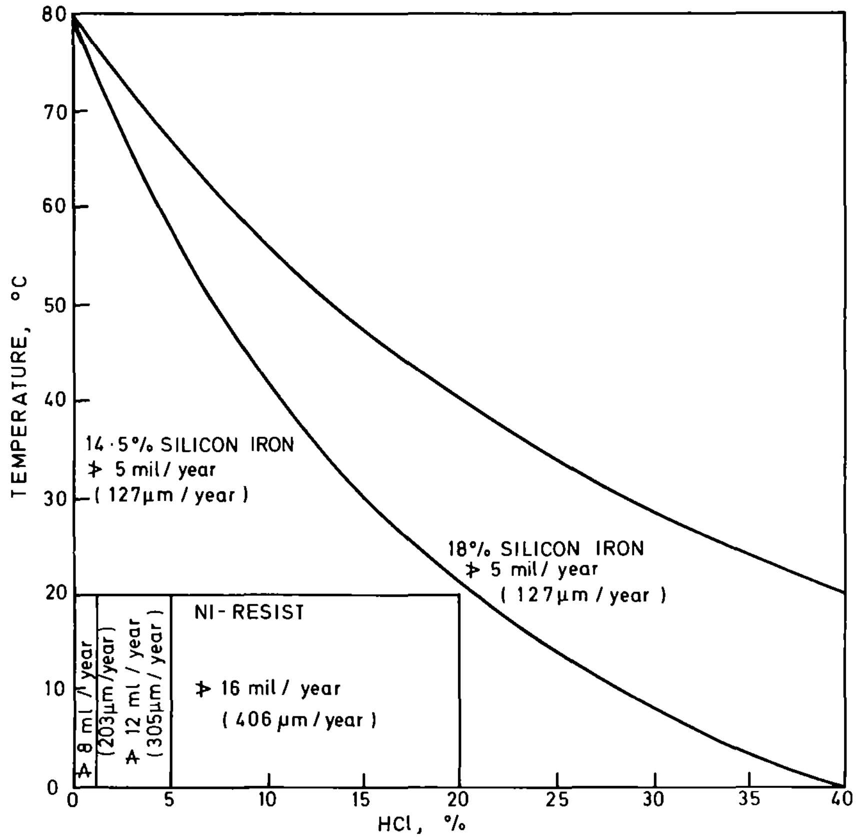
Cast irons. Corrosion rate of high-nickel and high-silicon molybdenum alloy irons compared to 18-8 stainless steel when exposed to hydrochloric acid at various concentrations. Source: "Physical and Corrosion Properties," in *Source Book on Ductile Iron*, A.H. Rauch, Ed., American Society for Metals, Metals Park, OH, 1977, 367.



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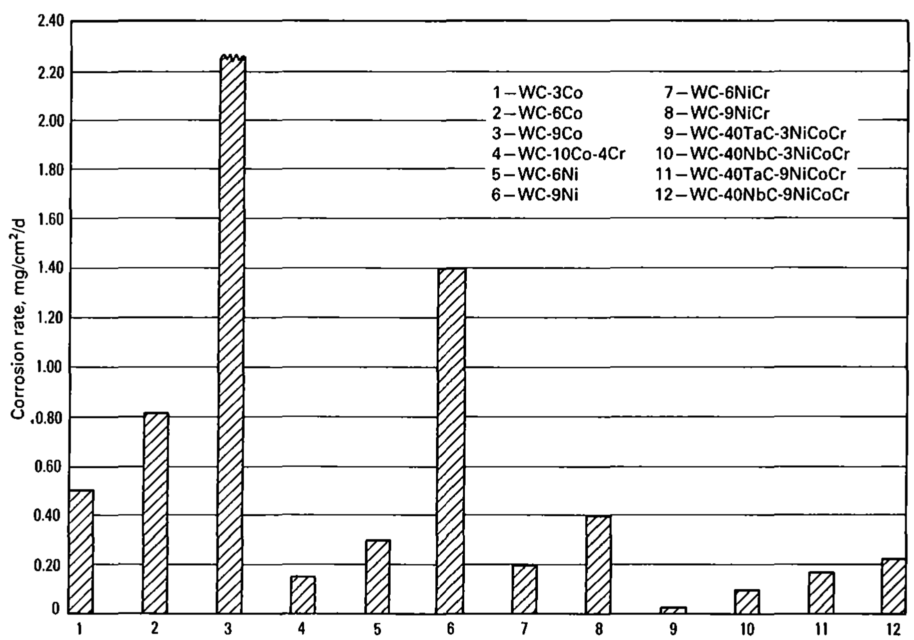
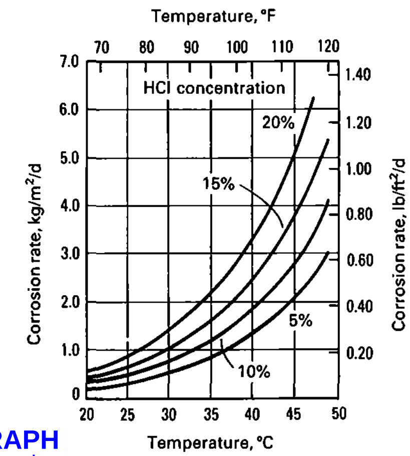
Cast irons. Corrosion rates of cast iron in hydrochloric acid. Source: H.T. Angus, *Cast Iron: Physical and Engineering Properties*, 2nd ed., Butterworths, London, 1976, 323.



Cemented carbides. Corrosion resistance of cemented carbides in 22% hydrochloric acid at room temperature. Source: E. Kay, T. Bader, Ch. Hohenrainer, L. Schmid, and R. Glatzle, Korrosionsresistent hochverschlei festye Hartmetalle, *Werkst. Korros.*, May 1986, and E. Kay and L. Schmid, "New Hardmetal Alloys with Improved Erosion and Corrosion Resistance," as reported in *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 852.



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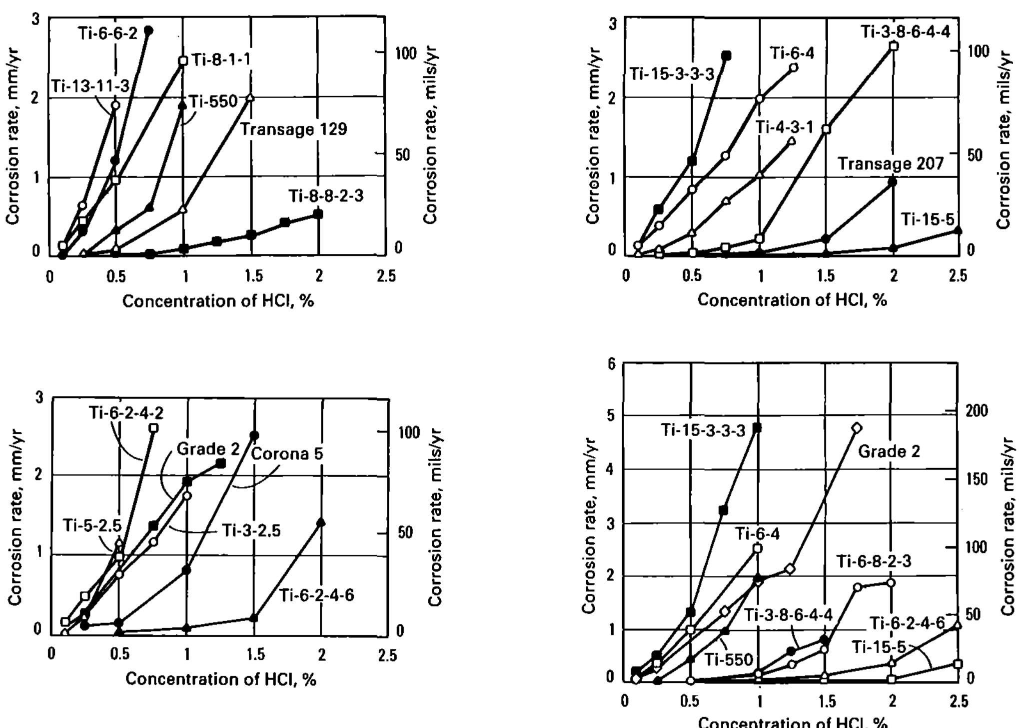
Low-carbon steel. Effect of temperature on corrosion of low-carbon steel in uninhibited hydrochloric acid. Source: Chemical Processing Industry.



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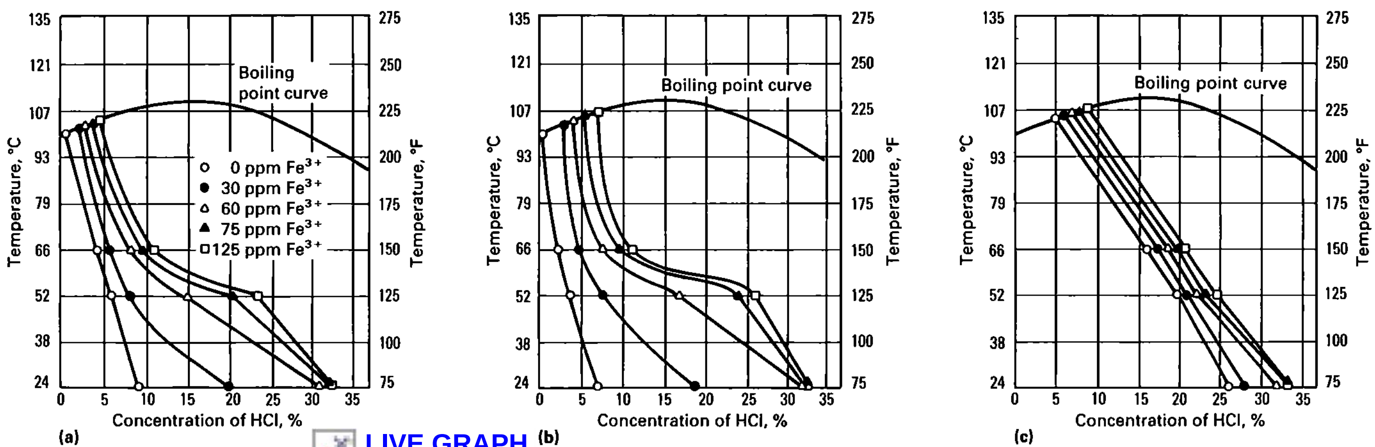
Titanium. General corrosion of annealed titanium alloys in naturally aerated hydrochloric acid solution. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 680.



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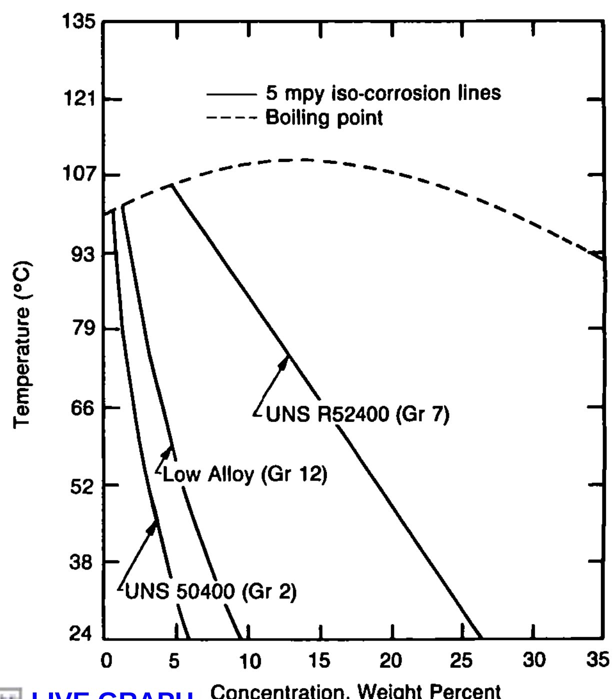
Titanium. Effect of minute ferric ion concentrations on the useful corrosion resistance of grade 2 titanium (a), grade 12 titanium (b), and grade 7 titanium (c) in naturally aerated hydrochloric acid solutions. 0.127-mm/yr (5-mils/yr) isocorrosion lines are shown. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 683.



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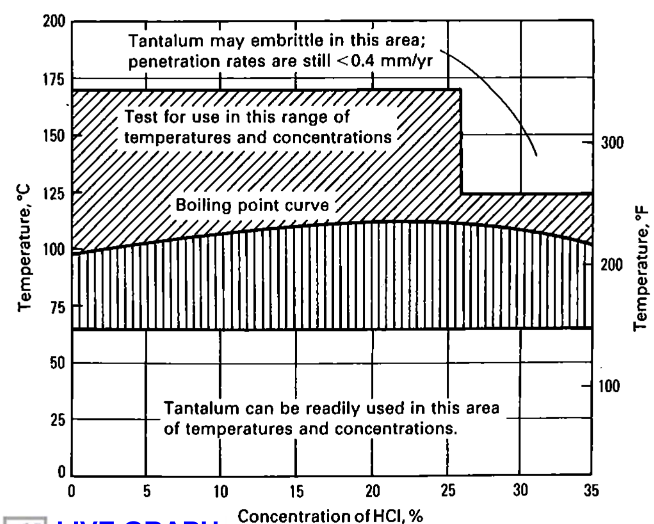
Titanium. Corrosion of titanium alloys in naturally aerated hydrochloric acid solutions. Source: T.F. Degnan, "Materials Construction for Hydrochloric Acid," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986, 170.



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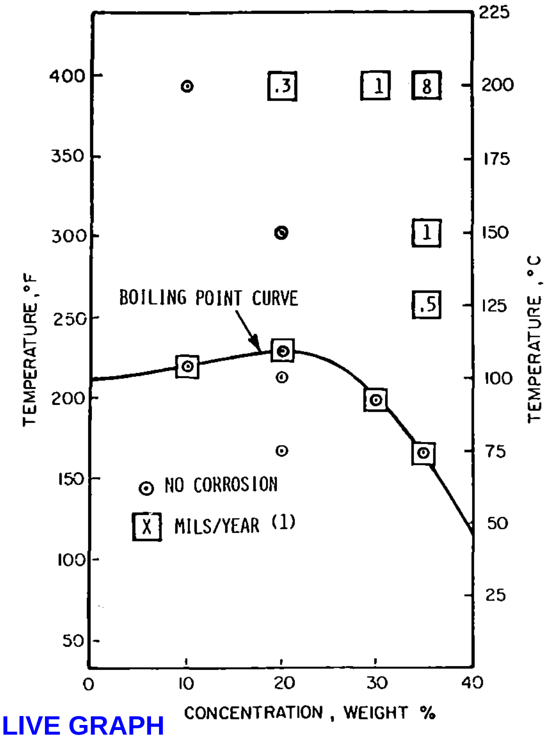
Tantalum. Corrosion of tantalum in hydrochloric acid at various concentrations and temperatures. Source: M. Stern and C.R. Bishop, Corrosion and Electrochemical Behavior, in *Columbium and Tantalum*, F.T. Sisco and E. Epremian, Ed., John Wiley & Sons, New York, 1963, and "Tantalum, Corrosion Data, Comparative Charts and Coating Characteristics," General Technologies Corporation.



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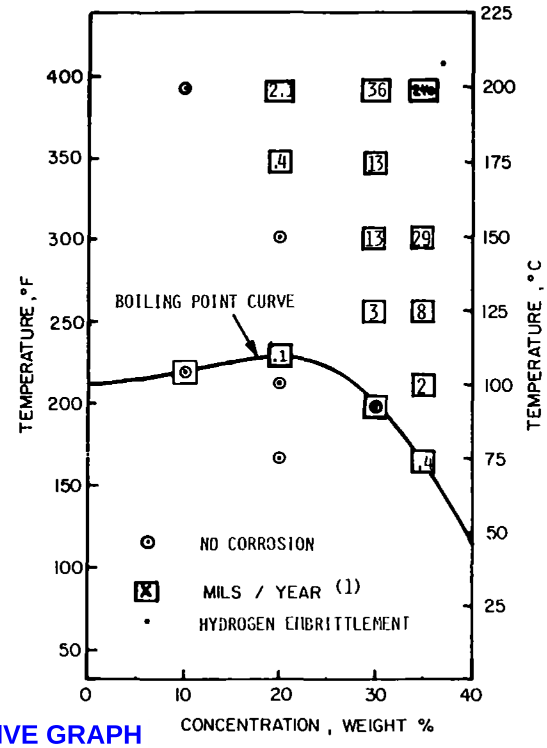
Tantalum. Corrosion resistance of tantalum in hydrochloric acid. Source: R.H. Burns, F.S. Shuker, Jr., *et al.*, "Industrial Applications of Corrosion-Resistant Tantalum, Niobium, and Their Alloys," in *Refractory Metals and Their Industrial Applications* (STP 849), R.E. Smallwood, Ed., ASTM, Philadelphia, 1984, 60.



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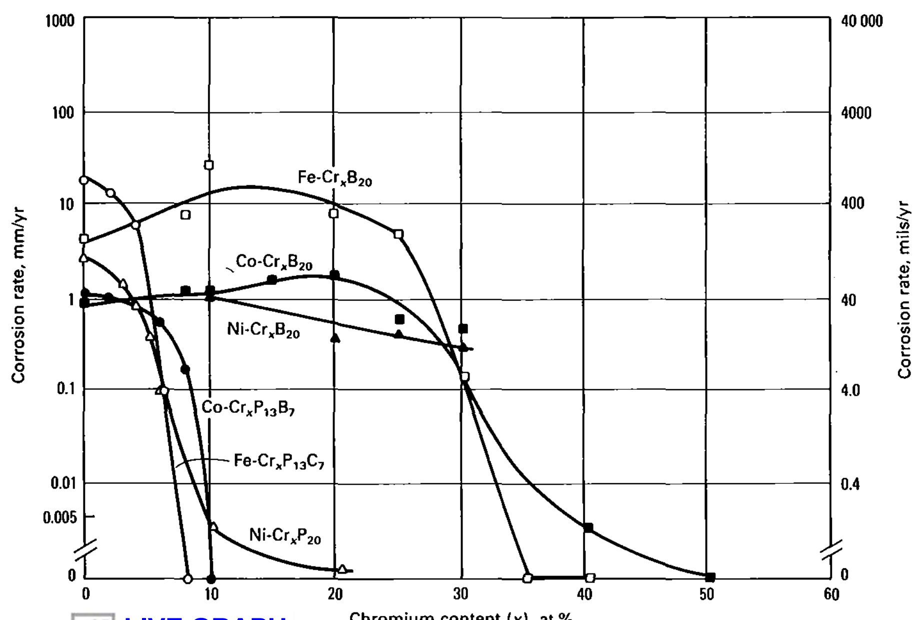
Tantalum. Corrosion resistance of KBI alloy 40 in hydrochloric acid (KBI Alloy 40 is a Ta-40Nb alloy). Source: R.H. Burns, F.S. Shuker, Jr., *et al.*, "Industrial Applications of Corrosion-Resistant Tantalum, Niobium, and Their Alloys," in *Refractory Metals and Their Industrial Applications* (STP 849), R.E. Smallwood, Ed., ASTM, Philadelphia, 1984, 59.



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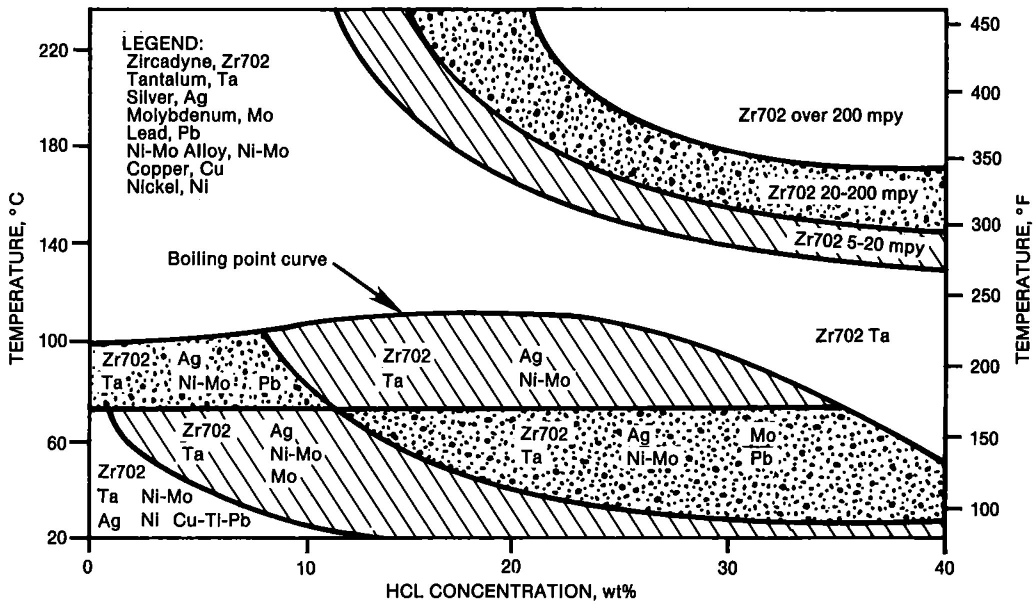
Various alloys. The influence of chromium content on the corrosion rates of iron-, cobalt-, and nickel-base amorphous alloys in 1*N* hydrochloric acid. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 867.



Corrosion resistance of materials to hydrochloric acid

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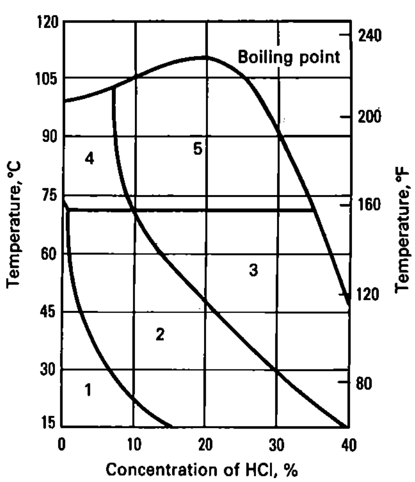
Various alloys. Corrosion resistance of various materials to hydrochloric acid. These materials exhibit a corrosion rate of less than 20 mils/yr, except for zirconium and tantalum, which have corrosion rates of less than 5 mils/yr. Source: Teledyne Wah Chang Albany.



a)

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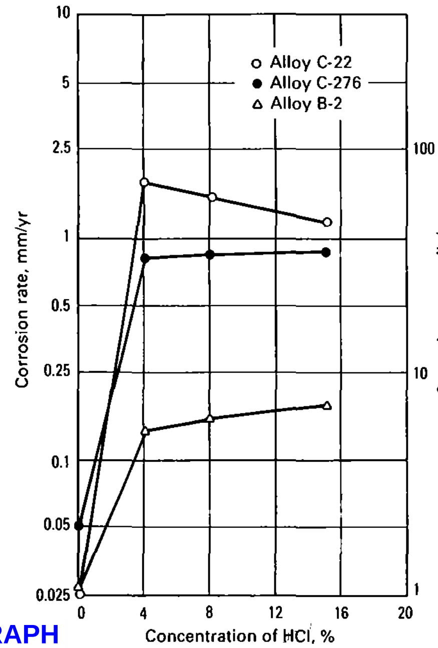
Metals with reported corrosion rates of <0.5 mm/yr (<20 mils/yr) in HCl

Zone 1	Zone 2	All zones (including 5)
ACI CN-7M(a)(c)(f)	Silicon bronze(b)(f)	Platinum
Monel 400(b)(c)(f)	Silicon cast iron(c)(g)	Tantalum
Copper(b)(c)(f)	**Zone 3**	Silver(c)(f)
Nickel 200(b)(c)(f)	Silicon cast iron(c)(g)	Zirconium(c)(f)
Silicon bronze(b)(c)(f)	**Zone 4**	Hastelloy B-2(c)(f)
Silicon cast iron(c)(g)	Tungsten	Molybdenum(c)(f)
Tungsten	Titanium, grade 7(e)	
Titanium, grade 7		
Titanium, grade 2(d)		

(a) <2% HCl at 25 °C (75 °F). (b) No aeration. (c) No $FeCl_3$ or $CuCl_2$ contamination. (d) <10% HCl at 25 °C (75 °F). (e) <5% HCl at boiling temperature. (f) No free chlorine. (g) Contains chromium, molybdenum, and nickel

b)

Various alloys. Various alloys for hydrochloric acid service. Source: D.L. Gaver, Ed., *Corrosion Data Survey*, 6th ed., National Association of Corrosion Engineers, Houston, 1985, 180-181.



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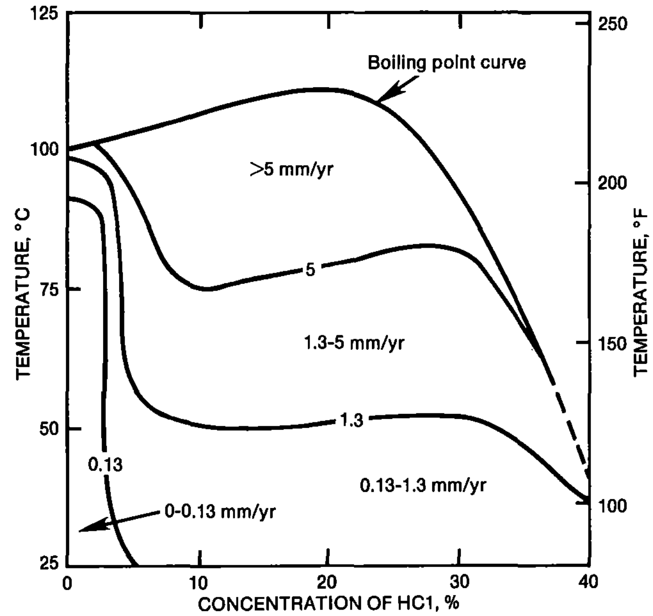
Various alloys. Effect of hydrochloric acid on the corrosion of various alloys in 15% hydrochloric acid at 80 °C. Source: N. Sridhar, Paper 182, presented at "Corrosion/86," National Association of Corrosion Engineers, Houston, 1986.



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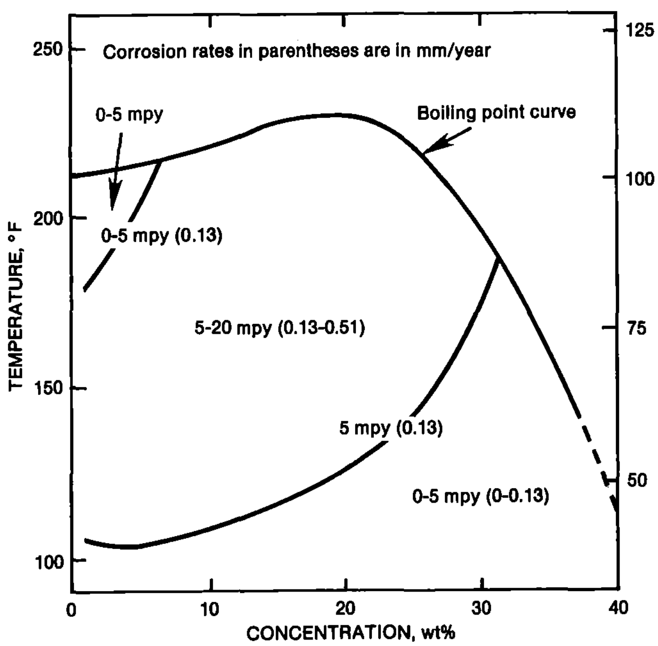
Hastelloy G. Isocorrosion diagram for Hastelloy G in hydrochloric acid. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1163.



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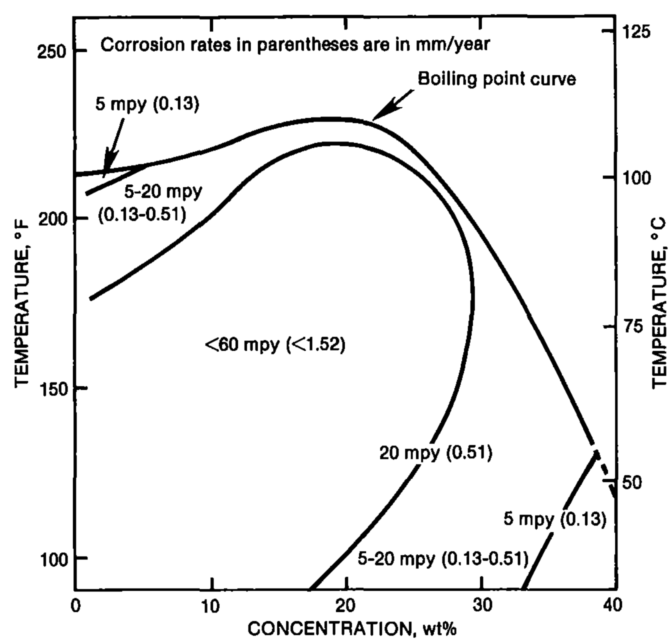

b) LIVE GRAPH
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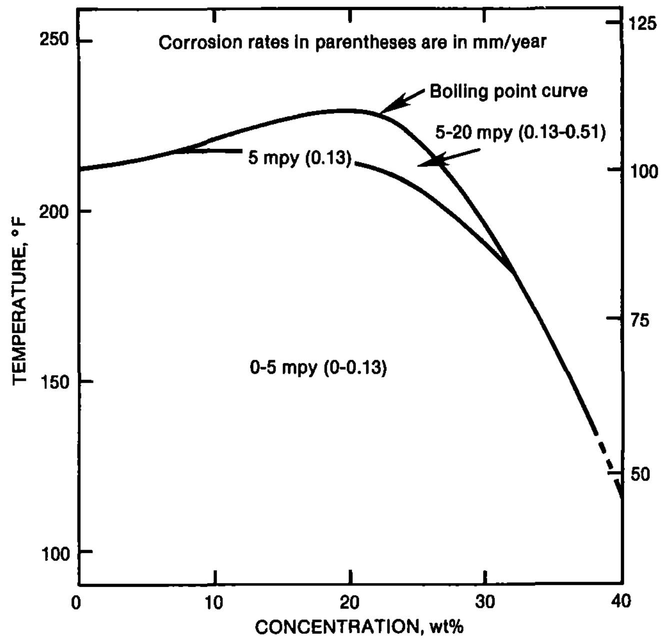

c) LIVE GRAPH
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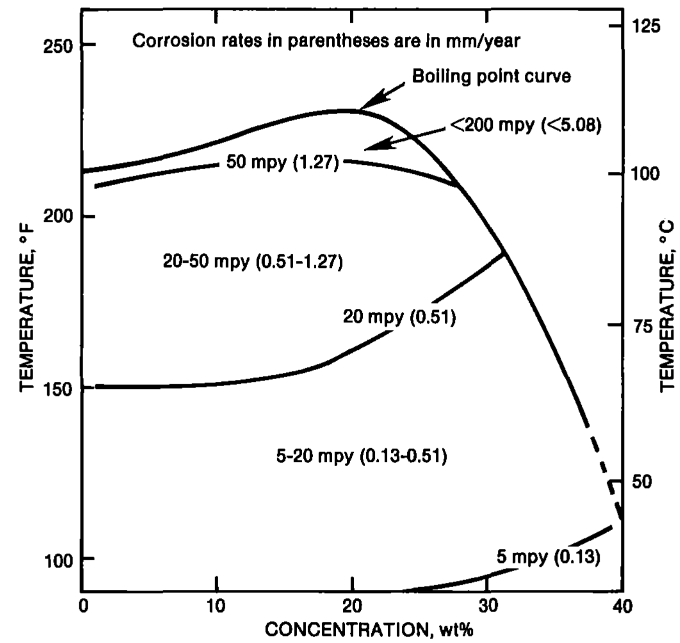

d) LIVE GRAPH
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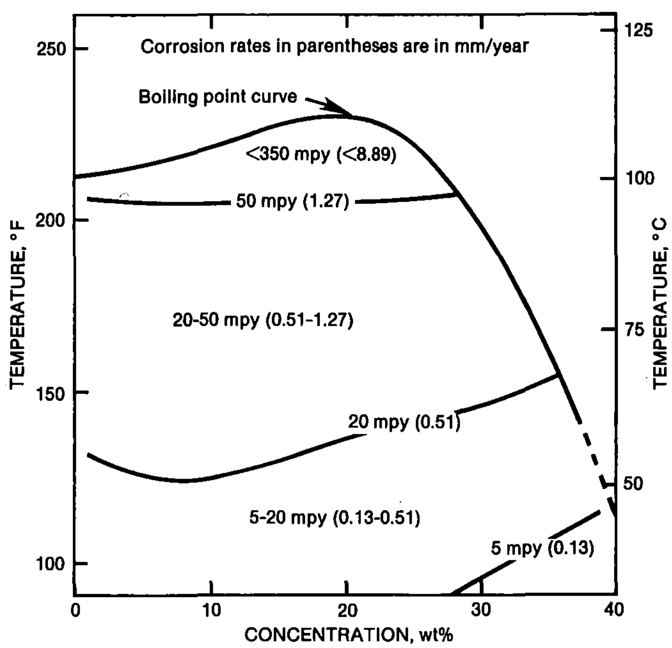

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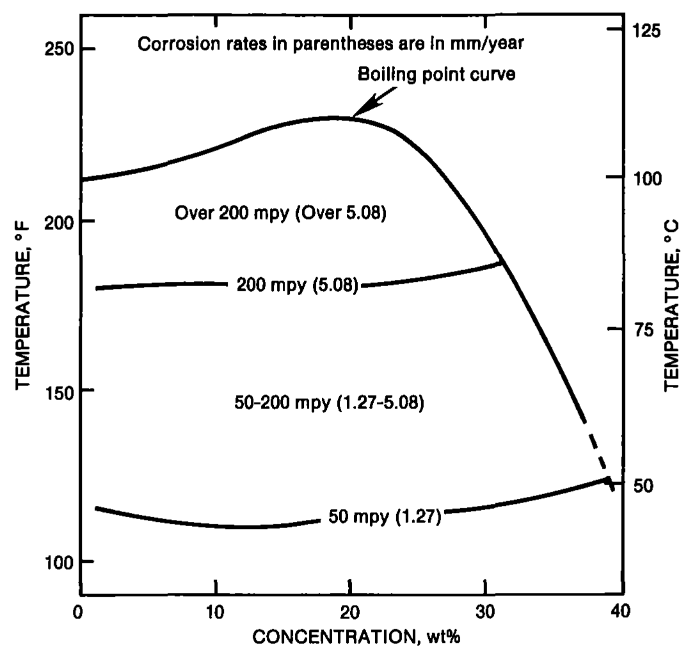

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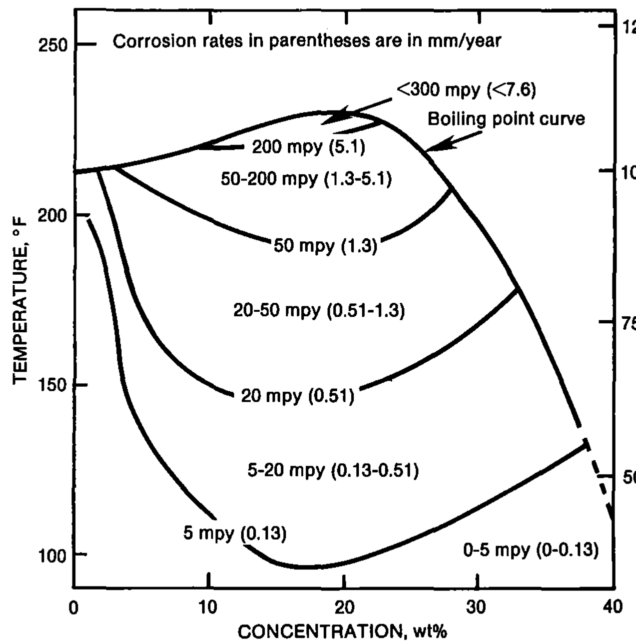
f)

Hastelloy B-2. Resistance to (a) hydrochloric acid, (b) hydrochloric acid purged with oxygen, (c) hydrochloric acid purged with nitrogen, (d) hydrochloric acid with 50 ppm ferric ions, (e) hydrochloric acid with 100 ppm ferric ions, and (f) hydrochloric acid with 500 ppm ferric ions. All test specimens were solution heat-treated and in the unwelded condition. Source: Haynes International, 1984.



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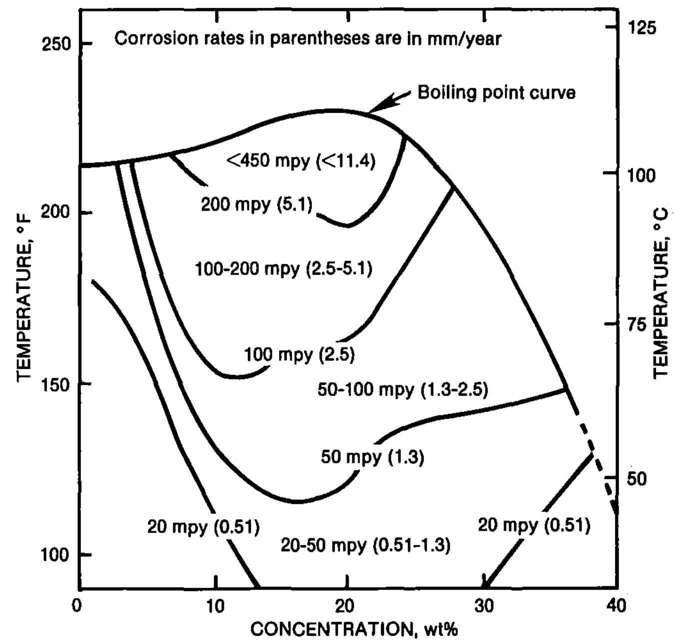

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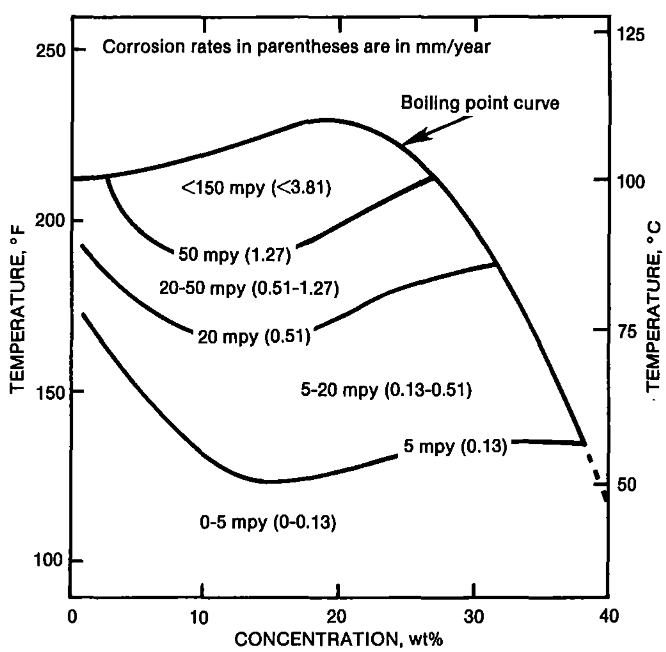

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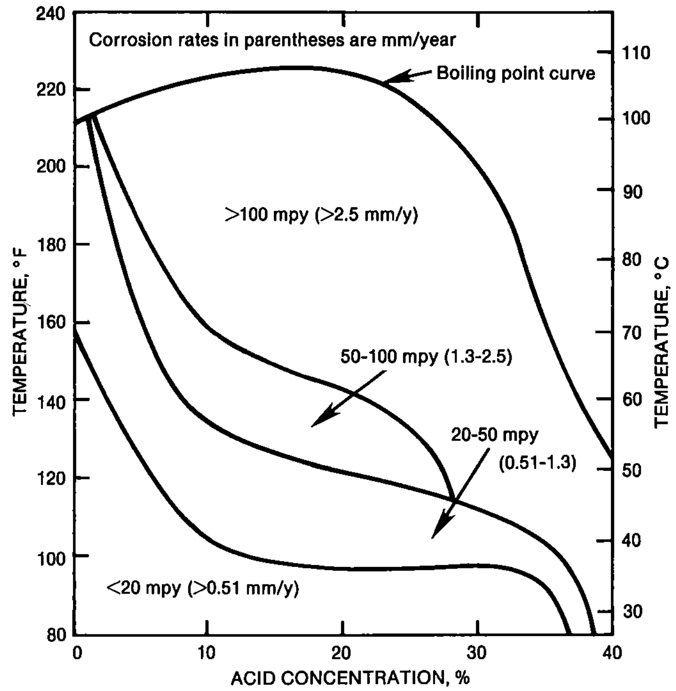
Hastelloy C-276. Resistance to (a) hydrochloric acid, (b) hydrochloric acid purged with oxygen, and (c) hydrochloric acid purged with nitrogen. Test specimens for (a) and (b) were heat treated at 1121 °C (2050 °F), rapid quenched, and in the unwelded condition; for (c) test specimens were solution heat-treated and in the unwelded condition. Source: Haynes International, 1984.



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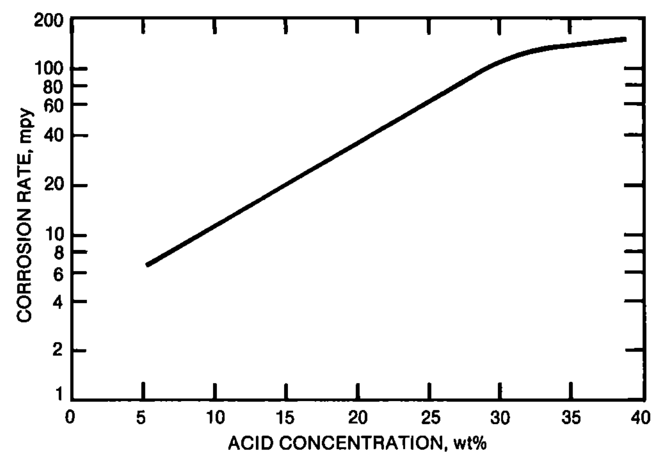

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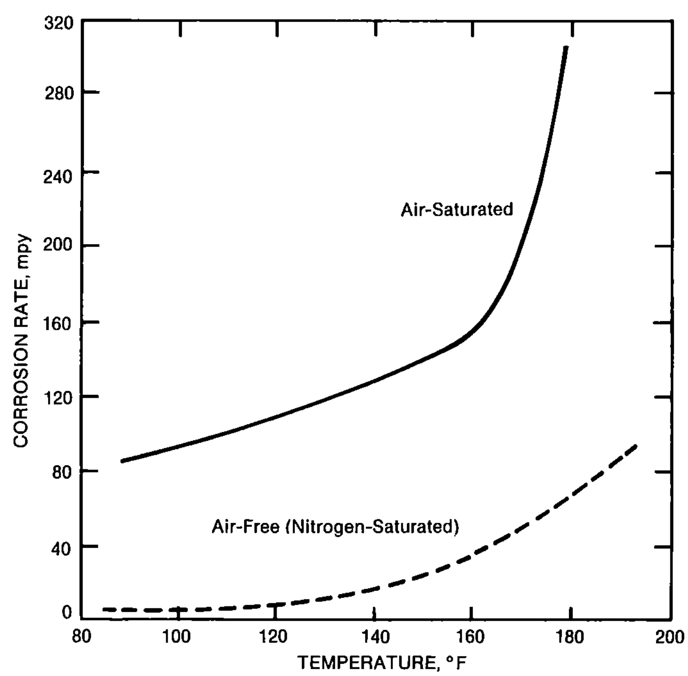

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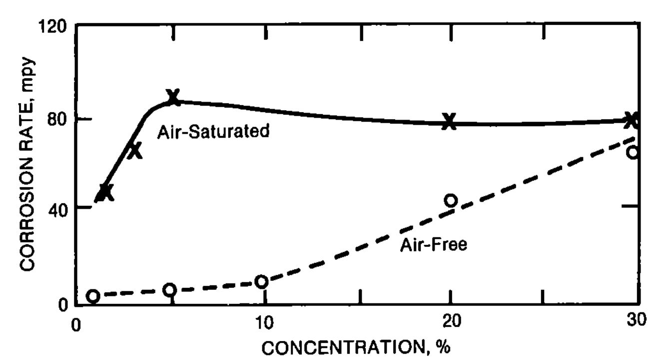

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Nickel alloys. Corrosion rates in hydrochloric acid for (a) Incoloy alloy 825, based on laboratory tests in pure acid; (b) Inconel alloy 600, at room temperature; (c) Monel alloy 400 in 5% hydrochloric acid; and (d) Nickel 200 in hydrochloric acid at 86 °F (the air-free samples were nitrogen saturated). Source: Inco Alloys International.

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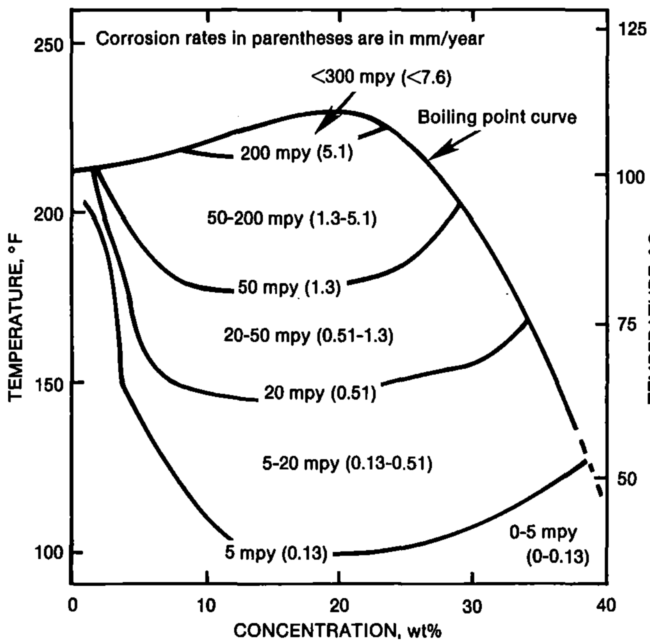

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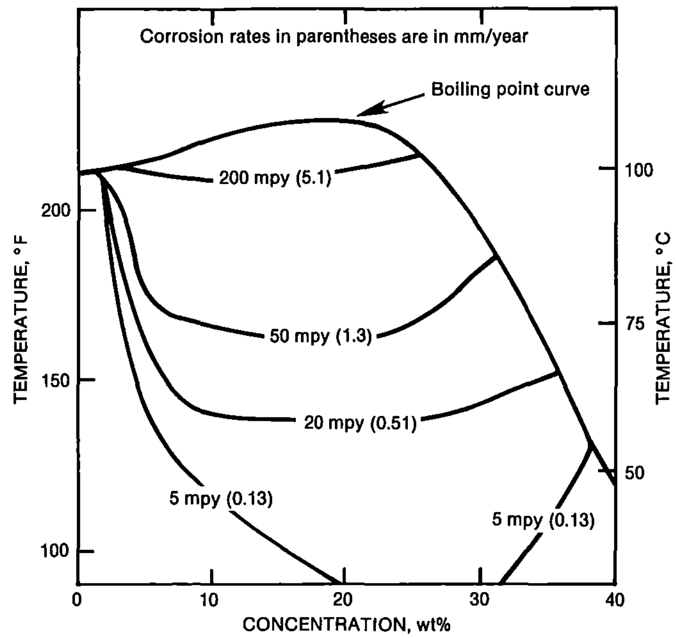

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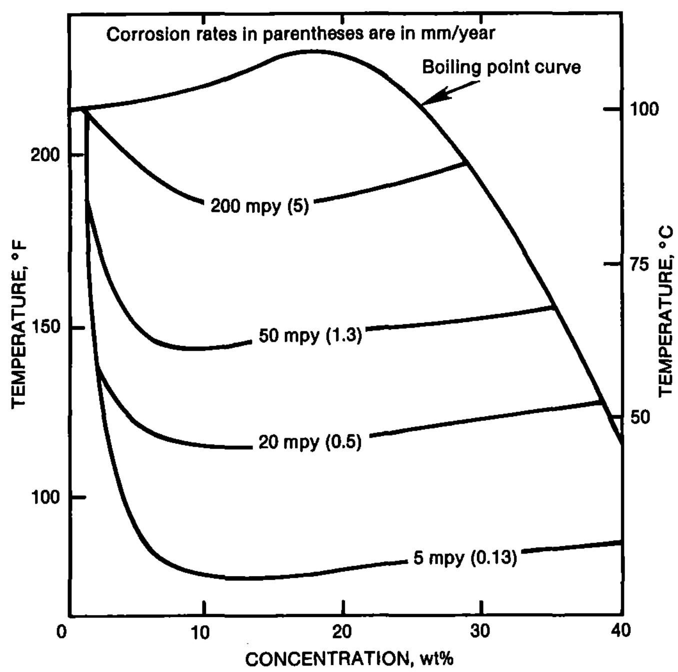

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Nickel alloys. Resistance to hydrochloric acid. (a) Hastelloy C-4, test specimens were solution heat-treated at 1066 °C (1950 °F), rapid quenched and in the unwelded condition. (b) Hastelloy C-22, test specimens were solution heat-treated and in the unwelded condition; and (c) Hastelloy G-30, test specimens were heat-treated at 1177 °C (2150 °F), rapid quenched and in the unwelded condition. Source: Haynes International.

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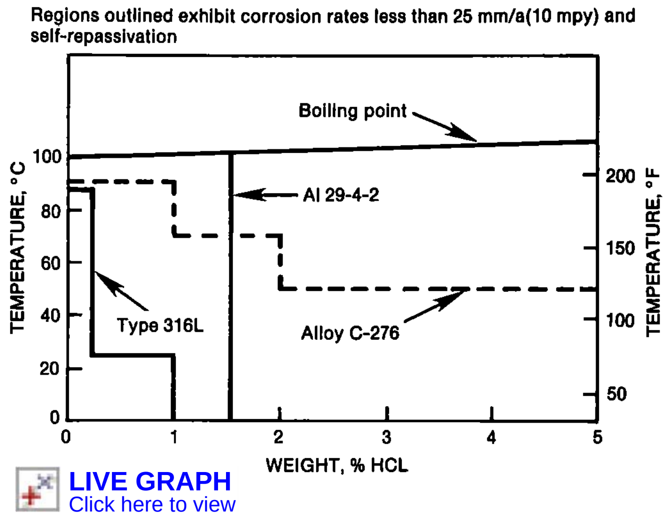
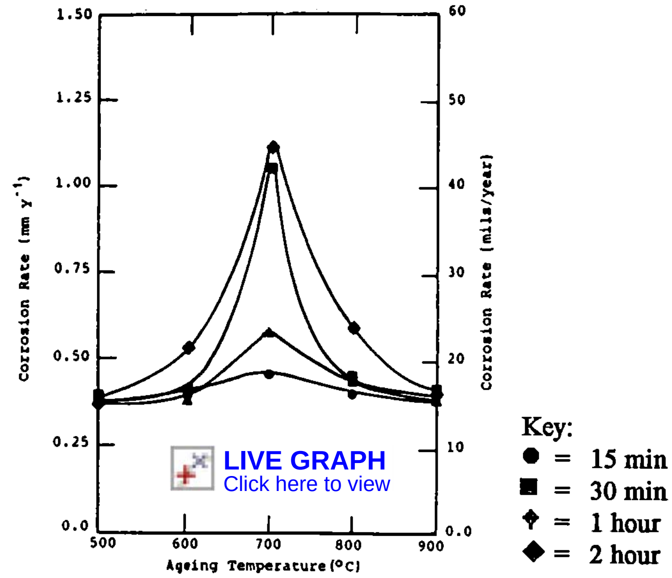


Nickel and nickel-base alloys. Comparison of corrosion resistance of AL 29-4-2, Nickel alloy C-276, and type 316L stainless steel in dilute hydrochloric acid. Source: Allegheny Ludlum Corporation, 1982.



Hastelloy B-2. Effect of aging temperature, 500 to 900 °C (932 to 1652 °F), and times at temperature on the corrosion rate in boiling 20% HCl. Ref. 275

Hydrocyanic Acid

Also known as formonitrile, hydrogen cyanide and prussic acid, HCN is a highly toxic liquid that has the odor of bitter almonds and boils at 25.6 °C. It is used to manufacture cyanide salts, acrylonitrile, and dyes, and as a fumigant in agriculture.

Corrosion Behavior of Various Metals and Alloys in Hydrocyanic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Hydrofluoric Acid and Hydrogen Fluoride

Anhydrous hydrogen fluoride (AHF) and hydrofluoric acid (aqueous hydrogen fluoride) are of great industrial importance. Hydrofluoric acid (HF), a colorless, fuming, poisonous, highly corrosive, extremely reactive liquid, is used in large quantities for pickling of stainless steels and other metals, acid treating of wells, and etching of glass. Other uses include production of aluminum fluoride and synthetic cryolite for aluminum production; production of fluorinated organics such as aerosol propellants, special-purpose solvents, refrigerants, and plastics; formulation of atomic-energy feed materials; manufacture.of elemental fluorine; preparation of fluorides and fluoborates; dissolving of ores; and cleaning of stone and brick.

Anhydrous hydrogen fluoride is the foundation of the multibillion dollar fluorocarbon industry, which encompasses essentially all refrigerants, fire-extinguishing agents, ultrasonic cleaning fluids, fluorocarbon plastics, and fluorocarbon elastomers. A popular process for alkylation of petroleum to enhance yields of gasoline depends on the use of anhydrous hydrogen fluoride.

Both aqueous hydrofluoric acid and anhydrous fluoride are hazardous chemicals that are highly corrosive to skin, eyes, lungs, and mucous membranes. Fluoride salts, although added to potable waters to prevent tooth decay, are toxic in higher concentrations. Painful, persistent burns and often deep-seated ulcerations result from contact with aqueous hydrofluoric acid or anhydrous hydrogen fluoride, and inhalation of high concentrations of the vapors causes lung damage. The Occupational Safety and Health Administration has ruled that an employee's exposure to hydrofluoric acid vapor in any 8-h work shift of a 40-h work week shall not exceed a time-weighted average of 3 ppm hydrofluoric acid vapor by volume.

Anhydrous hydrogen fluoride is manufactured by the reaction of H_2SO_4 and calcium fluoride (CaF_2) in horizontal kiln-like reactors, usually constructed of steel with a high-nickel alloy liner at the feed and discharge ends. The popular Buch process premixes the CaF_2 and H_2SO_4 in a high-nickel alloy mixer that reduces corrosion of the steel reactor. The reaction is endothermic and therefore requires a source of heat.

Information of suitable materials of construction for handling hydrofluoric acid is presented in various sources. However, many factors that are not shown on charts can influence the performance of these materials, and adequate experience or testing under the proposed conditions is necessary to avoid serious corrosion problems. The duration of the test is important because most metals form protective films or scales that decrease initially high rates to the low rates found in commercial use. Therefore, the validity of short-term rates should be discounted unless the validity of the short-term test has been confirmed by longer tests.

Materials Commonly Used. Materials in common use in hydrofluoric acid service are listed in the Materials Selection for Hydrofluoric Acid Service table. This information, although not exhaustive, can be considered to be a valid guide for initial design and cost estimates of equipment to be used for handling most commercial hydrofluoric acids and is reliable for final material selection for service in acids known to be of normal commercial quality and to contain no impurities that might result in unusual corrosion. The information in this table assumes that the acid will be received and stored at ambient temperatures only. Where no temperature range is given, the data should be considered to be valid only for ambient-temperature service.

Unsuitable Materials. Metals considered unsuitable for hydrofluoric acid service can be divided into four groups: velocity-sensitive, hydrogen-sensitive, component-sensitive, and notch-sensitive.

Velocity-sensitive metals include copper, copper alloys other than copper nickels, and straight chromium stainless steels (such as type 410).

Hydrogen-sensitive metals are further divided into two subgroups—hydrogen embrittlement sensitive and hydrogen blistering sensitive. Metals sensitive to hydrogen embrittlement are steels and iron alloys, and welds and heat-affected zones with hardness of 22 HRC or higher. Fine-grain steels (without inclusion-shape control) are sensitive to hydrogen blistering.

Component-sensitive metals comprise high-zinc uninhibited brasses, and alloys of, or containing appreciable amounts of, silicon, tantalum, zirconium, titanium, and niobium. Notch-sensitive metals are free-machining steel, high-phosphorous steels, and cast irons.

High-Temperature Gas. A series of short-term corrosion tests conducted on the rate of attack of hot, gaseous anhydrous hydrogen fluoride on various metals showed that Nickel 200, Monel 400, and Inconel 600 all have useful resistance to gaseous anhydrous hydrogen fluoride at temperatures up to 600 °C (1110 °F) and that austenitic stainless steels are inferior to carbon steel in this regard. Although corrosion rates were exaggerated and distorted by the short 3- to 15-h test periods, other data confirm the general ranking of the materials. Although the tests were run for only 36 h, the results agree with experience.

Inconel 600 has been successfully used in the hydrofluorination of metal oxides at temperatures of 370 to 590 °C (700 to 1095 °F). Nickel 200 and the copper-nickel alloys are susceptible to intergranular embrittlement by sulfur compounds at temperatures above about 300 °C (570 °F). Trace amounts of these compounds are present in commercial anhydrous hydrogen fluoride. Inconel 600 resists embrittlement and has been successfully used at these temperatures in gaseous hydrofluoric acid environments. It should be noted that many nickel alloys, including Hastelloy C-276 and Inconel 625, undergo metallurgical changes, such as aging or long-range ordering at temperatures above 400 to 500 °C (750 to 930 °F). Hardness and susceptibility to hydrogen embrittlement also increase. Inconel 600 is relatively unaffected.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon and Alloy Steels. Hardened carbon and alloy steels exhibit hydrogen embrittlement, and steel plate and pipelines suffer hydrogen

blistering and stepwise cracking in the presence of either aqueous or anhydrous hydrofluoric acid. Corrosion of steel by nonoxidizing acids is accompanied by the formation of atomic hydrogen, which then either combines to form gaseous molecular hydrogen or is absorbed by the steel. Because of the small quantities of sulfides and arsenic that it contains, hydrofluoric acid inhibits the formation of molecular hydrogen and thus promotes absorption of atomic hydrogen into the steel. Once absorbed, the atomic hydrogen may migrate to dislocations in hardened steel and cause hydrogen embrittlement or may recombine at laminations or inclusions and produce blistering.

Carbon steels have useful corrosion resistance in the range of 64 to 100% hydrofluoric acid. Resistance to aqueous acid is limited to ambient temperatures. Liquid anhydrous hydrogen fluoride is commonly handled in carbon steel at temperatures up to 65 °C (150 °F). Gaseous anhydrous hydrogen fluoride is less corrosive and can be handled at temperatures up to 300 °C (570 °F).

Although Interstate Commerce Commission regulations permitted transportation of aqueous hydrofluoric acid of 60% or greater concentration in steel containers that were passivated with 59% acid, one study found that even passivated drums developed excessive hydrogen pressure from corrosion with 60% acid. The results of this testing indicate that the minimum concentration should be 64%. In practice, the closest commercial grade is 70% hydrofluoric acid, and the maximum recommended temperature for storage and handling is 30 °C (90 °F).

Alloy steels often have higher corrosion rates than carbon steels. In one case, a section of low-temperature pipe (ASTM A333, grade 9) containing nickel and copper was installed in a carbon steel piping system handling a mixture of organics and anhydrous hydrogen fluoride at a temperature above ambient. The section failed by uniform thinning, whereas the carbon steel fittings on either end were relatively unaffected.

It has been found that dilute acids (1.4 to 1.7*N* hydrofluoric, sulfuric, perchloric, and hydrochloric) used for chemical cleaning of heat exchangers corrode iron and carbon steel at about equivalent rates, but that hydrofluoric acid causes exceptionally high corrosion rates on steels containing 1.25 to 18% Cr (ASTM A335 grades and type 430 stainless steel).

Many failures of alloy steel fasteners in anhydrous hydrogen fluoride service have occurred, particularly with fasteners made of the Cr-Mo steel ASTM A193, grade B7. A better choice for high-strength fasteners is grade B7M, which is the same as grade B7, but tempered to a lower hardness (201 to 235 HB). However, bolts made of this material are subject to cracking under stresses beyond the yield point in hydrofluoric acid service. In addition, the above-mentioned range of hardness is difficult for manufacturers to meet while still fulfilling minimum tensile requirements.

Stainless Steels. The use of stainless steels in hydrofluoric acid service is generally rather limited. Austenitic stainless steels have good resistance to liquid anhydrous hydrogen fluoride at somewhat elevated temperatures. Unpublished data show corrosion rates of less than 0.13 mm/yr (<5 mils/yr) for type 304 stainless steel at 100 °C (212 °F), but high corrosion rates at 150 °C (300 °F). Type 304 stainless steel has good resistance to anhydrous hydrogen fluoride gas up to 200 °C (390 °F). Cast ACI CF-8M stainless steel is used for anhydrous hydrogen fluoride pumps. However, both type 304 stainless steel and carbon steel have been known to fail by direct impingement of anhydrous hydrogen fluoride streams.

Austenitic stainless steels have limited resistance to dilute hydrofluoric acid. Type 304 stainless steel has poor resistance to any significant concentration, but type 316 has useful resistance at ambient temperatures and concentrations below 10%.

Cold-worked type 303 stainless steel failed rapidly when used as a fastener material in a hydrofluoric acid plant. Cold-worked type 304 stainless steel fasteners (ASTM A193, grade B8, class 2) had few failures.

Annealed austenitic stainless steels are resistant but not immune to stress-corrosion cracking by hydrofluoric acid. In one study, types 304 and 316 both failed from transgranular cracking in impure 12% hydrofluoric acid at 70 °C (160 °F); type 304 failed in hot 40 to 50% hydrofluoric acid. However, these conditions are more severe than are reasonable for the use of stainless steels in hydrofluoric acid. This study also reported that cold-worked 18-8 stainless steel did not suffer stress-corrosion cracking in a 7-day test in anhydrous hydrogen fluoride at 70 °C (150 °F). Another study showed that the threshold Cl^- ion concentration necessary to cause intergranular stress-corrosion cracking of sensitized type 304 stainless steel was greatly reduced by the presence of fluorides.

Higher alloys such as 20Cb-3 stainless steel and Incoloy 825 have good resistance to all concentrations of hydrofluoric acid at ambient temperatures and to 0 to 10% concentrations at 70 °C (160 °F). The preferred material for pumps and valves for 70% hydrofluoric acid at ambient temperatures and for valve trim for anhydrous hydrogen fluoride is ACI CN-7M casting alloy.

Aluminum. Hydrofluoric acid is corrosive to aluminum alloys, and for most alloy compositions, its corrosive action is uniform and imparts a bright and silvery appearance to the metal. Hydrofluoric acid has been used as an etchant in the preparation of decorative patterns on aluminum.

Copper. In general, the use of copper in hydrofluoric acid service, regardless of hydrofluoric acid concentration, is limited by its susceptibility to aeration and velocity effects. The major exception is alloy C71500 (copper nickel, 30%), which has good resistance to both aqueous and anhydrous hydrofluoric acid. Unlike some other copper alloys, C71500 is not sensitive to velocity effects. Red brass (85% Cu minimum, remainder mostly zinc) has been used for pipes, fittings, and valves handling hydrofluoric acid, but only for acid concentrations of 1% or less. In this application, limited aeration had no significant adverse effect, but metal failure occurred at a site involving alternate wet and dry conditions.

Lead. The resistance of lead to corrosion by hydrofluoric acid is only fair. However, lead is used to handle hydrofluoric acid because it is the only low-priced metal that has adequate corrosion resistance. The corrosion rate in this acid (if it is free of air) is less than 510 μm/yr (20 mils/yr) for a wide range of temperatures and concentrations. Hydrofluoric acid rapidly attacks lead when dilute, but has little effect at strengths of 52 to 70%.

Magnesium. Magnesium is rapidly attacked by all mineral acids except for hydrofluoric acid and chromic acid. Hydrofluoric acid does not attack magnesium to an appreciable extent, because it forms an insoluble, protective magnesium fluoride film on the magnesium; however, pitting develops at low acid concentrations. With increasing temperature, the rate of attack increases at the liquid line, but to a negligible extent elsewhere.

Molybdenum. Molybdenum has good resistance to both aqueous and anhydrous hydrofluoric acid. The corrosion rates of molybdenum in 25

to 50% hydrofluoric acid at 100 °C (212 °F) are 0.4 to 0.5 mm/yr (16 to 20 mils/yr) in aerated acid. Rates in the absence of air are so small as to be negligible.

Nickel and Nickel Alloys. Nickel 200 is less resistant than Monel 400 to aqueous hydrofluoric acid. Also, oxygen has a greater accelerating effect on corrosion of Nickel 200. In aqueous hydrofluoric acid, use of Nickel 200 is limited to completely air-free systems below 80 °C (175 °F). Although there are reports of stress-corrosion cracking of Nickel 200 in aqueous hydrofluoric acid, they appear to be related to such impurities as cupric fluoride ($CuFe_2$). Nickel 200 is one of the most resistant alloys to hot anhydrous hydrogen fluoride vapor, but it may be embrittled by sulfur compound impurities.

Monel 400. Monel 400 is used extensively in hydrofluoric acid alkylation units and in the manufacture and handling of hydrofluoric acid. It has excellent resistance to liquid hydrofluoric acid over the entire concentration range in the absence of oxygen to at least 150 °C (300 °F).

Monel 400 is subject to stress-corrosion cracking when exposed to wet vapors of hydrofluoric acid in the presence of oxygen. Cracking is intergranular. In one investigation, Monel 400 showed transgranular stress-corrosion cracking in the vapor phase of dilute hydrofluoric acid solutions (up to 0.5% hydrofluoric acid) at temperatures up to 95 °C (200 °F). The cracking susceptibility did not depend on the presence of oxygen, and no cracking was found in the liquid phase.

The mechanism of cracking was unknown until it was found that aqueous hydrofluoric acid solutions containing appreciable concentrations of cupric chloride ($CuCl_2$) would cause rapid cracking of stressed Monel 400. The least resistant nickel-copper composition corresponds to that of Monel 400 (33% Cu). Copper-nickel alloys with 30% or less nickel are resistant.

The reason that stress-corrosion cracking is usually limited to the vapor phase rather than liquid is the enrichment of a thin layer of aqueous hydrofluoric acid in the vapor with copper fluoride corrosion products. The presence of oxygen accelerates corrosion and forms CuF_2 from CuF. The much greater dilution of corrosion products prevents reaching a critical concentration of CuF_2 in the liquid phase.

Inconel 600. Inconel 600 is resistant to dilute aqueous hydrofluoric acid at ambient temperatures and to anhydrous hydrogen fluoride. It has been used in valves and other equipment in place of Monel 400 to avoid possible stress-corrosion cracking. It is the most widely used alloy for hot hydrofluoric acid vapors, combining excellent chemical resistance and comparatively good metallurgical stability.

High-Performance Nickel Alloys. The Hastelloy alloys (C-276, B-2, G, and G-3) and Inconel 625 all have good-to-excellent resistance to aqueous and anhydrous hydrofluoric acid and to high-temperature hydrofluoric acid vapors. The presence of air or oxidizing agents can cause fairly high corrosion rates in hot aqueous acids.

Niobium. Niobium, although resistant to most organic and mineral acids, is nonresistant to both aqueous and anhydrous hydrofluoric acid in even trace amounts. Metals and welding products that contain appreciable amounts of niobium will suffer accelerated corrosion by hydrofluoric acid under certain circumstances. The presence of several percent niobium in Monel 400 welds has been known to cause preferential weld attack.

Noble Metals. The noble metals, including gold, silver, and platinum, are all more or less unaffected by anhydrous hydrogen fluoride or by aqueous hydrofluoric acid of any concentration at ambient temperatures and, in most cases, to the boiling point or higher. Silver is widely used in stills, heating coils, and condensers for pure hydrofluoric acid. The resistance of silver to hydrofluoric acid can be affected by the presence of sulfides and oxygen. Silver is not passivated by hydrofluoric acid, as it is by the other halide acids. Platinum and gold are unaffected at high temperatures.

Tantalum. Although immune to attack by almost all acids, tantalum is nonresistant to both aqueous and anhydrous hydrofluoric acid, even in trace amounts. Under certain circumstances, hydrofluoric acid will cause accelerated corrosion of metals and welding products that contain appreciable amounts of tantalum.

In fact, hydrofluoric acid is the best solvent for tantalum. The rate of attack varies from slow for dilute acid to rapid for concentrated solutions. The rate of attack by hydrofluoric acid can be greatly accelerated by the addition of HNO_3 and other oxidizing agents, such as H_2O_2. Embrittlement of the metal due to the absorption of atomic (nascent) hydrogen can occur when the metal is attacked by hydrofluoric acid. However, when sufficient HNO_3 is present, hydrogen embrittlement does not occur, even after nearly all of the tantalum is dissolved—for example, by severe pickling. The rate of hydrogen absorption is greatly reduced in dilute hydrofluoric acid if the tantalum is made positive by impressing 2 to 10 V on the material in an electrolytic cell. Embrittlement by hydrogen does not occur when tantalum is made positive. In solution of hydrofluoric acid, which prevents the formation of the protective oxide film, tantalum is less noble than zinc, manganese, aluminum, and zirconium.

Attack on tantalum apparently does not occur in chromium plating baths containing F^-. In one test, a corrosion rate of 0.0005 mm/yr (0.02 mil/yr) was observed on a sample placed in a chromium plating bath for 2 months. The solution contained 40% chromium trioxide (CrO_3) and 0.5% F^- ion at a temperature of 55 to 60 °C (130 to 140 °F).

The corrosion resistance of tantalum-tungsten alloys was also studied in 50% KOH at 30 and 80 °C (85 and 175 °F), 20% hydrofluoric acid at 20 °C (70 °F), and $KOH{:}3K_3Fe(CN)_6$ mixture (concentration not given).

In the hydroxide solutions, a maximum corrosion rate was obtained at about 60 at.% tantalum. Although the alloy system reportedly represents a continuous series of solid solutions, a maximum electrical resistance also found at the same composition. In 20% hydrofluoric acid solution, the tantalum-tungsten alloy system essentially exhibits the relatively low corrosion rates associated with tungsten, except when the tantalum concentration exceeds 80 at.%, at which concentration corrosion increases markedly. Alloys containing more than 18% tungsten show no corrosion in 20% hydrofluoric acid, thus offering an advantage over pure tantalum. Other tests have been conducted on tantalum and tantalum-tungsten alloys having tungsten contents ranging from 8.7 to 20.4% in 20% hydrofluoric acid. This work showed that tantalum and tantalum-tungsten alloys containing less than about 20% tungsten were more susceptible to attack by 20% hydrofluoric acid than was previously reported. Tantalum-tungsten alloys showed little improvement over tantalum when tested in the $KOH{:}3K_3Fe(CN)_6$ mixture.

Tin. Although the rate of attack is slow, tin reacts readily with hydrofluoric acid.

Titanium. Hydrofluoric acid solutions (as well as anhydrous hydrofluoric acid) can aggressively attack titanium and titanium alloys over the full range of concentrations and temperatures. Metals and welding

products containing appreciable amounts of titanium will under certain circumstances suffer accelerated corrosion by hydrofluoric acid. Although the addition of oxidizing species, such as HNO_3, will tend to reduce corrosion and retard hydrogen uptake in hydrofluoric acid solutions, significant rates of attacks still prevail. Inhibition of corrosion can be achieved in very dilute acid fluoride solutions when an excess of complexing metal ions is present. In the absence of these complexing metal ions, solutions containing more than 20 ppm F^- may attack titanium when solution pH falls below 6 to 7.

Zirconium. Zirconium is attacked by aqueous and anhydrous hydrofluoric acid in even the lowest concentrations. Metals and welding products that contain appreciable amounts of zirconium will suffer accelerated corrosion by hydrofluoric acid under certain circumstances.

Materials Selection for Hydrofluoric Acid Service

Material	Acid concentration, %	Applications	Comments
Steel (100% up to 66 °C, or (150 °F; 70% up to 32 °C, or 90 °F)	70-100(a)	All welded tanks 13-mm (½-in.) minimum wall. A thickness allowance of 6 mm (¼ in.) for acid in the 70 to 80% range is suggested. Pipe: extra heavy, seamless or welded. Fittings: extra heavy, forged, slag-free welds. Valves: forged steel, outside screw and yoke. Pressure gauges, pumps, centrifugal or positive displacement	Hydrogen embrittlement of hardened steels may be encountered in storage facilities or in subsequent process equipment. Alloy steel bolts (ASTM A-193 B7) have cracked. A few failures of "as-welded" mild steel are known in HF alkylation reactors. Steel with a hardness greater than 22 HRC and/or plastically strained are subject to hydrogen embrittlement failure. Vessels should be either stress relieved or hardness of welds and heat-affected zones should be controlled (NACE Recommended Practice RP-04-72) or both. Alloy steel bolts should also be hardness controlled (ASTM A-193 B7M) and should not be over tightened. Hydrogen blistering can occur, predominantly in fine-grain practice steels such as ASTM A-516. Inclusion shape-controlled plate steels should be used to minimize blistering. Alloy steel piping (A-333 Grade 9) corrodes more rapidly. Cast iron, ductile iron, or malleable iron fittings have been found to be unacceptable. Trim in valves and pumps should be of a resistant alloy: CN-7M, nickel-copper Alloy 400 (UNS N04400) or cobalt-base hard-facing alloy.(b) Steel parts in contact become cemented together by iron-fluoride corrosion products.(c) Bourdon tubes or diaphragms should be welded steel or a resistant alloy. Down to 60% strength, acid may be stored in mild steel if inhibited with at least 1.5% H_2SO_4
Stainless steel (ACI CF-8M)	80-100	Pumps	Reported to be better than cast steel. Limited to ambient temperature
Nickel-chromium-iron alloy 600 (UNS N06600)	80-100	Equipment	Used in place of nickel-copper Alloy 400 (UNS N04400) in AHF to avoid stress-corrosion cracking
Alloy 20 (d) (ACI CN-7M)	80-100	Pumps and valves	...
Copper in acid free of air and silicon dioxide	All	Tubes and gaskets	Reported to be highly velocity-sensitive and is useful only in low velocity and stagnant conditions. However, copper 90/10 copper-nickel (UNS C70600), and silicon bronze did not de-nickelify in hot dilute (1 to 5%) HF, while 70/30 copper-nickel (UNS C71500) and Alloy 400 (UNS (N04400) did
Nickel-copper alloy 400 (UNS N04400)	All	Pipe, fittings, heat exchangers, vessels, and valves	This alloy of 66% nickel and 31.5% copper is widely used and can be used over the entire range of concentrations at temperatures up to the atmospheric boiling point if "air-free" conditions are maintained. Where air or oxygen cannot be excluded, corrosion rates, usually in the range of 0.07 to 0.4 mm/yr (3 to 15 mils/yr), occur at room temperature. At higher temperatures with air present, corrosion rates are usually in the range of 0.1 to 1.2 mm/yr (5 to 50 mils/yr). Severe liquid level attack can also occur in the presence of air. In addition to higher corrosion rates, this alloy is subject to stress-corrosion cracking in moist, aerated vapors of hydrogen fluoride and to a much lesser extent in aerated solutions of the acid. Dissolved copper accelerates attack. In practice, occurrence of stress-corrosion cracking may either be avoided by complete exclusion of oxygen or may be minimized by stress relieved welded or cold-formed parts at 535 °C (1000 °F) minimum followed by slow cooling. Niobium-free (d) welding products are preferred. Relatively free of velocity effects
Alloy B-2 (UNS N10665)	All	...	Adverse effects of dissolved oxygen similar to those of Alloy 400. This alloy type reported to be susceptible to intergranular corrosion if not solution annealed
70/30 copper-nickel (UNS C71500)	All	...	Similar to the nickel-copper alloy above in unaerated aqueous hydrofluoric acid, but possesses only limited resistance in aerated solutions. Resistant to stress cracking
Tetrafluorethylene, fluoroethylene propylene, perfluoroalkane, and monochlorotrifluorethylene	A	Linings and gaskets	Subject to permeation. Rate depends upon thickness and temperature. Not normally a problem with thicker linings such as used in lined pipe
Fluoroelastomer	All	Gaskets	...

(a) Most HF is manufactured from sulfuric acid and fluorspar. Trace impurities in either reagent may find their way into the product acid. This may cause some unusual failures. (b) Alkylation plant pumps are carbon steel with nickel-copper Alloy 400 (UNS N04400) and cobalt alloy (AMS 5373B and AMS 5387) seal rings. (c) The adherent corrosion product film on carbon steel is protective and reduces corrosion rates under velocity conditions. (d) Niobium carbides and, to a lesser extent, titanium carbides are attacked by AHF. Welds in alloys that contain these elements have been known to be preferentially attacked.

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum alloy 1100	A91100	...	Anhydrous gas	...	500 (930)	...	4.9 (192)	...	186
Aluminum alloy 1100	A91100	...	Anhydrous gas	...	600 (1110)	...	14.6 (576)	...	186
Aluminum alloy	...	...	Anhydrous	...	15-25 (60-80)	...	.52 (20.4)	...	186
Aluminum alloy	...	...	Anhydrous	...	80-90 (180-190)	...	25 (976)	...	186
Carbon and alloy steels									
1010 steel	G10100	...	...	58	23	25 d	3.0 (120)	...	186
1010 steel	G10100	...	...	60	...	...	2.5 (100)	...	186
1010 steel	G10100	...	...	61	...	...	2.1 (82)	...	186
1010 steel	G10100	...	...	62	...	...	1.5 (59)	...	186
1010 steel	G10100	...	...	63	...	...	0.24 (9.6)	...	186
1010 steel	G10100	...	...	64	...	...	0.05 (2.0)	...	186
1010 steel	G10100	...	...	65	...	...	.006 (2.2)	...	186
1010 steel	G10100	...	...	67.5	...	...	0.05 (1.9)	...	186
1010 steel	G10100	...	...	69.9	...	...	0.06 (2.5)	...	186
1010 steel	G10100	...	Anhydrous	...	25-40 (80-100)	...	.16 (6.2)	...	186
1010 steel	G10100	...	Anhydrous	...	55 (130)	...	.35 (14)	...	186
1010 steel	G10100	...	Anhydrous	...	80-90 (180-190)	...	2.3 (89)	...	186
1010 steel	G10100	...	Anhydrous	100	15-25 (60-80)	40 d	.07 (2.8)	...	186
1020 steel	G10200	...	Anhydrous gas	...	500 (930)	...	15.5 (612)	...	186
1020 steel	G10200	...	Anhydrous gas	...	550 (1020)	...	14.6 (576)	...	186
1020 steel	G10200	...	Anhydrous gas	...	600 (1110)	...	7.6 (300)	...	186
ASTM A106 carbon steel	G10100	...	1.7*N*	...	45 (115)	3 h	26 (1000)	...	31
ASTM A335, grade P11 (1.5 Cr-0.25 Mo)	K11597	...	1.7*N*	...	45 (115)	3 h	290 (11400)	...	31
ASTM A335, grade P22 (2 Cr-1 Mo)	K21590	...	1.7*N*	...	45 (115)	3 h	640 (25000)	...	31
ASTM A335, grade P5 (5 Cr-0.5 Mo)	K51545	...	1.7*N*	...	45 (115)	3 h	290 (11400) min	...	31
ASTM A335, grade P9 (10 Cr-1 Mo)	S50400	...	1.7*N*	...	45 (115)	3 h	330 (13000)	...	31
Low alloy steel	...	...	Anhydrous	...	15-25 (60-80)	...	.15 (6.0)	...	186
Low alloy steel	...	...	Anhydrous	...	25-40 (80-100)	...	.14 (5.9)	...	186
Low alloy steel	...	...	Anhydrous	...	80-90 (180-190)	...	2 (78)	...	186
Copper and alloys									
70-30 cupronickel	C17500	...	May be considered in place of a copper metal when some property, other than corrosion resistance, governs its use	...	...	...	Good	...	93
70-30 cupronickel	C71500	...	Anhydrous	...	16-27 (60-80)	...	180 (7)	...	186
70-30 cupronickel	C71500	...	Anhydrous	...	25-40 (80-100)	...	.05 (2)	...	186
70-30 cupronickel	C71500	...	Anhydrous	...	55 (130)	...	.008 (0.3)	...	186
70-30 cupronickel	C71500	...	Anhydrous	...	80-90 (180-190)	...	.25 (10)	...	186
70-30 cupronickel	C71500	...	Anhydrous	...	82-88 (180-190)	...	255 (10)	...	186
70-30 cupronickel	C71500	...	Gaseous	...	...	...	0.4 (16)	...	186
70-30 cupronickel	C71500	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	38	112 (234)	4 d	0.09 (3.5)	...	146
70-30 cupronickel	C71500	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	48	108 (226)	4 d	0.05 (2)	...	146
70-30 cupronickel	C71500	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	48	108 (226)	4 d	0.08 (3)	...	146
70-30 cupronickel	C71500	...	Liquid phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.07 (2.6)	...	146

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
70-30 cupronickel	C71500	...	Liquid phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.18 (7)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	0.50 (20)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	0.45 (18)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	0.90 (36)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	0.73 (29)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.30 (12)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.18 (7)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.18 (7)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.33 (13)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.28 (11)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.33 (13)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.45 (18)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.43 (17)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.43 (17)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.48 (19)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	0.75 (30)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	1.33 (53)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	0.73 (29)	...	146
70-30 cupronickel	C71500	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	0.55 (22)	...	146
70-30 cupronickel	C71500	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.08 (3.2)	...	146
70-30 cupronickel	C71500	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.03 (1)	...	146
70-30 cupronickel	C71500	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.03 (1)	...	146
70-30 cupronickel	C71500	...	Vapor phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.07 (2.9)	...	146
70-30 cupronickel	C71500	...	Vapor phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.30 (12)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	2.00 (80)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	2.08 (83)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	3.90 (156)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	3.30 (132)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	1.08 (43)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	1.00 (40)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.75 (30)	...	146

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
70-30 cupronickel	C71500	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	1.20 (48)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	1.05 (42)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	1.35 (54)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	1.05 (42)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	1.35 (54)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	1.53 (61)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	1.63 (65)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	1.50 (60)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	3.60 (144)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	4.25 (170)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	2.95 (118)	...	146
70-30 cupronickel	C71500	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	2.28 (91)	...	146
80-20 cupronickel	C71000	...	Anhydrous	...	25-40 (80-100)	...	.13 (5.2)	...	186
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	38	112 (234)	4 d	0.06 (2.4)	...	146
90-10 cupronickel	C70600	...	Liquid phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.07 (2.9)	...	146
90-10 cupronickel	C70600	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.28 (11)	...	146
90-10 cupronickel	C70600	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.33 (13)	...	146
90-10 cupronickel	C70600	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.05 (2)	...	146
90-10 cupronickel	C70600	...	Vapor phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.08 (3)	...	146
90-10 cupronickel	C70600	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	1.32 (53)	...	146
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	Anhydrous	...	15-25 (60-80)	...	.25 (10)	...	186
Admiralty brass	C44300	...	Anhydrous	...	25-40 (80-100)	...	.33 (12.8)	...	186
Admiralty brass	C44300	...	Anhydrous	...	55 (130)	...	.01 (.4)	...	186
Admiralty brass	C44300	...	Anhydrous	...	80-90 (180-190)	...	.5 (20)	...	186
Admiralty brass, antimonial	C44400	...	Anhydrous	...	16-27 (60-80)	...	225 (10)	...	186
Admiralty brass, antimonial	C44400	...	Anhydrous	...	27-38 (80-100)	...	480 (19)	...	186
Admiralty brass, antimonial	C44400	...	Anhydrous	...	82-88 (180-190)	...	510 (20)	...	186
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	Anhydrous	...	15-25 (60-80)	...	.37 (14.4)	...	186
Ampco 8, aluminum bronze	C61300	...	Generally suitable. Conditions such as aeration or temperature could restrict use	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Electrolytic copper	C11000	...	Anhydrous gas	...	500 (930)	...	1.5 (60)	...	186
Electrolytic copper	C11000	...	Anhydrous gas	...	600 (1110)	...	1.2 (48)	...	186
Electrolytic copper	C11000	...	Anhydrous	...	15-25 (60-80)	...	.33 (12.9)	...	186
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Questionable	...	93
Phosphor bronze	...	...	Anhydrous	...	15-25 (60-80)	...	.5 (20)	...	186
Phosphor bronze	...	...	Anhydrous	...	25-40 (80-100)	...	.48 (18.8)	...	186
Phosphor bronze	...	...	Anhydrous	...	80-90 (180-190)	...	1.5 (60)	...	186
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	Anhydrous	...	27-38 (80-100)	...	480 (19)	...	186
Phosphor bronze, 5% Sn	C51000	...	Anhydrous	...	82-88 (180-190)	...	1525 (60)	...	186
Phosphor bronze, 5% Sn	C51000	...	Anhydrous	100	16-27 (60-80)	...	510 (20)	...	186
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	Anhydrous	...	15-25 (60-80)	...	.76 (30)	...	186
Red brass	C23000	...	Anhydrous	...	25-40 (80-100)	...	0.4 (16)	...	186
Red brass	C23000	...	Anhydrous	...	80-90 (180-190)	...	1.3 (50)	...	186
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Irons and alloys									
Armco iron	...	...	1.7*N*	...	45 (115)	3 h	14 (551)	...	31
Duriron	F47003	...	Anhydrous	...	25-40 (80-100)	...	1.1 (45)	...	186
Miscellaneous									
Gold	P00016	...	...	40	Room	...	0.05 (2) max	...	8
Iridium	...	...	...	40	Room	...	Resistant	...	29
Magnesium G	...	...	Anhydrous gas	...	500 (930)	...	13.8 (542)	...	186
Magnesium	...	...	...	5-60	Room	...	Resistant	...	119
Magnesium	...	...	Anhydrous	...	15-25 (60-80)	...	.13 (5.2)	...	186
Magnesium	...	...	Anhydrous	...	25-40 (80-100)	...	.43 (17.1)	...	186
Magnesium	...	...	Anhydrous	...	55 (130)	...	Resistant	...	186
Magnesium	...	...	Anhydrous	...	80-90 (180-190)	...	Resistant	...	186
Magnesium	...	...	In liquid	50	...	...	.21 (8.4)	...	186
Magnesium	...	...	In liquid	65	...	...	.06 (2.3)	...	186
Magnesium	...	...	In vapor, nitrogen purged	50	...	...	.03 (1.2)	...	186
Magnesium	...	...	In vapor, nitrogen purged	65	...	...	.06 (2.3)	...	186
Osmium	...	...	...	40	Room	...	Resistant	...	17
Platinum	P04995	...	In liquid	50	...	35 d	Resistant	...	186
Platinum	P04995	...	In liquid	65	...	...	Resistant	...	186
Platinum	P04995	...	In vapor, nitrogen purged	50	...	...	Resistant	...	186
Platinum	P04995	...	In vapor, nitrogen purged	65	...	...	Resistant	...	186
Rhodium	P05990	...	...	40	Room	...	Resistant	...	29
Ruthenium	...	...	...	49	Room	...	Resistant	...	18
Silver	P07010	...	...	50 max	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	In liquid	50	...	...	.009 (.36)	...	186
Silver	P07010	...	In liquid	65	...	...	.018 (.72)	...	186
Silver	P07010	...	In liquid	70	...	...	.018 (.72)	...	186
Silver	P07010	...	In vapor, nitrogen purged	50	...	...	Resistant	...	186

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silver	P07010	...	In vapor, nitrogen purged	65	...	...	.003 (0.1) max	...	186
Silver	P07010	...	In vapor, nitrogen purged	70	...	...	.003 (0.1) max	...	186
Tin	...	...	...	40	100 (212)	...	Poor	...	94
Tin	...	...	...	40	20 (68)	...	Poor	...	94
Tin	...	...	...	40	60 (140)	...	Poor	...	94
Tin	...	...	...	75	100 (212)	...	Poor	...	94
Tin	...	...	...	75	20 (68)	...	Poor	...	94
Tin	...	...	...	75	60 (140)	...	Poor	...	94
Nickel and alloys									
Alloy 400	N04400	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	38	112 (234)	4 d	0.24 (9.5)	...	146
Alloy 400	N04400	...	Liquid phase, <5 ppm oxygen in nitrogen purge gas	48	108 (226)	...	0.28 (11)	...	146
Alloy 400	N04400	...	Liquid phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.43 (17)	...	146
Alloy 400	N04400	...	Liquid phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.56 (22)	...	146
Alloy 400	N04400	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	1.2 (46)	...	146
Alloy 400	N04400	...	Liquid phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	1.2 (48)	...	146
Alloy 400	N04400	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.79 (31)	...	146
Alloy 400	N04400	...	Liquid phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.7 (28)	...	146
Alloy 400	N04400	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.74 (29)	...	146
Alloy 400	N04400	...	Liquid phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.69 (27)	...	146
Alloy 400	N04400	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.86 (34)	...	146
Alloy 400	N04400	...	Liquid phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.86 (34)	...	146
Alloy 400	N04400	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	1.3 (53)	...	146
Alloy 400	N04400	...	Liquid phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	1.1 (43)	...	146
Alloy 400	N04400	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.17 (6.8)	...	146
Alloy 400	N04400	...	Vapor phase, <5 ppm oxygen in nitrogen purge gas	...	...	...	0.076 (3)	...	146
Alloy 400	N04400	...	Vapor phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.3 (12)	...	146
Alloy 400	N04400	...	Vapor phase, <500 ppm oxygen in nitrogen purge gas	...	...	...	0.1 (4)	...	146
Alloy 400	N04400	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	0.64 (25)	...	146
Alloy 400	N04400	...	Vapor phase, 10,000 ppm oxygen in nitrogen purge gas	...	...	...	1.9 (75)	...	146
Alloy 400	N04400	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	1.24 (49)	...	146
Alloy 400	N04400	...	Vapor phase, 1500 ppm oxygen in nitrogen purge gas	...	...	...	0.61 (24)	...	146
Alloy 400	N04400	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.46 (18)	...	146
Alloy 400	N04400	...	Vapor phase, 2500 ppm oxygen in nitrogen purge gas	...	...	...	0.23 (9)	...	146
Alloy 400	N04400	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	1.37 (54)	...	146
Alloy 400	N04400	...	Vapor phase, 3500 ppm oxygen in nitrogen purge gas	...	...	...	0.74 (29)	...	146

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 400	N04400	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	2.7 (107)	...	146
Alloy 400	N04400	...	Vapor phase, 4700 ppm oxygen in nitrogen purge gas	...	...	...	2.1 (83)	...	146
Alloy 400	N04400	Welded	Nitrogen blanketed	70	...	...	.013 (0.5)	...	186
Alloy 400	N04400	Welded	Oxygen blanketed	70	...	...	.58 (23)	...	186
Alloy 600	N06600	...	Solution not deaerated	5	70 (160)	4 h	.23 (9)	...	186
Alloy 625	N06625	...	...	...	80 (176)	...	0.50 (20)	...	212
Alloy 625	N06625	...	Liquid	40	50 (122)	30 d	1.63 (65)	...	225
Alloy 625	N06625	...	Solution not deaerated	2	70 (160)	4 h	.5 (20)	...	186
Alloy 625	N06625	...	Solution not deaerated	5	70 (160)	4 h	.4 (16)	...	186
Alloy 625	N06625	...	Vapor	40	50 (122)	30 d	4.40 (176)	...	225
Alloy 825	N08825	...	...	...	80 (176)	...	4.1 (162)	...	212
Alloy 825	N08825	...	Glass processing; field or plant test. Plus 50% sulfuric acid	50	Room to 60 (140)	4 d	0.7 (26)	...	89
Alloy 825	N08825	...	Mining; field or plant test; no aeration; slight to moderate agitation. Commercial grade	70	21 (70)	42 d	3.5 (140)	...	89
Alloy 825	N08825	...	Petroleum processing; field or plant test; no aeration; no agitation. Plus 71% organic fluorides, 19% benzene	6	135 (275)	226 d	1.0 (41)	...	89
Alloy B-2	N10665	...	Solution not deaerated	5	70 (160)	4 h	.38 (15)	...	186
Alloy C-22	N06022	...	Solution not deaerated	...	Boiling	4 h	.94 (37)	...	186
Alloy C-22	N06022	...	Solution not deaerated	...	Boiling	4 h	.84 (33)	...	186
Alloy C-22	N06022	...	Solution not deaerated	2	70 (160)	4 h	.23 (9.4)	...	186
Alloy C-22	N06022	...	Solution not deaerated	5	70 (160)	4 h	.34 (13.5)	...	186
Alloy C-276	N10276	...	Solution not deaerated	...	Boiling	4 h	.076 (3)	...	186
Alloy C-276	N10276	...	Solution not deaerated	...	Boiling	4 h	0.1 (4)	...	186
Alloy C-276	N10276	...	Solution not deaerated	2	70 (160)	4 h	.24 (9.5)	...	186
Alloy C-276	N10276	...	Solution not deaerated	5	70 (160)	4 h	.25 (10)	...	186
Alloy C-276	N10276	Welded	Nitrogen blanketed	70	23	36 d	.008 (0.3)	...	186
Alloy C-276	N10276	Welded	Oxygen blanketed	70	...	...	.94 (37)	...	186
Alloy C-4	N06455	...	Solution not deaerated	2	70 (160)	4 h	.43 (17)	...	186
Alloy C-4	N06455	...	Solution not deaerated	5	70 (160)	4 h	.38 (15)	...	186
Alloy G-3	N06985	...	Solution not deaerated	5	70 (160)	4 h	.5 (20)	...	186
Alloy G-30	N06030	...	...	...	80 (176)	...	0.13 (5)	...	212
Hastelloy B	N10001	...	...	25	23	5 d	.013 (5)	...	186
Hastelloy B	N10001	...	...	40	23	5 d	0.07 (2.6)	...	186
Hastelloy B	N10001	...	...	40	54 (130)	5 d	0.025 (1)	...	186
Hastelloy B	N10001	...	...	45	23	5 d	0.076 (3)	...	186
Hastelloy B	N10001	...	...	5	23	5 d	.01 (4)	...	186
Hastelloy B	N10001	...	...	60	23	5 d	0.04 (1.6)	...	186
Hastelloy B	N10001	...	...	98	34-44 (95-110)	5 d	0.1 (4)	...	186
Hastelloy B	N10001	...	Gaseous	...	...	...	.05 (2)	...	186
Hastelloy C	N10002	...	...	25	23	5 d	.13 (5)	...	186
Hastelloy C	N10002	...	...	40	23	5 d	.074 (2.9)	...	186
Hastelloy C	N10002	...	...	40	54 (130)	5 d	.025 (10)	...	186
Hastelloy C	N10002	...	...	45	23	5 d	.15 (6)	...	186
Hastelloy C	N10002	...	...	5	23	5 d	0.25 (1)	...	186
Hastelloy C	N10002	...	...	50	95 (205)	5 d	4.6 (180)	...	186
Hastelloy C	N10002	...	...	60	23	5 d	.09 (3.6)	...	186
Hastelloy C	N10002	...	...	65	70 (160)	5 d	.43 (17)	...	186
Hastelloy C	N10002	...	...	98	34-44 (95-110)	5 d	.025 (1)	...	186
Hastelloy C	N10002	...	Gaseous	100	500-600 (930-1110)	36 h	.008 (0.3)	...	186
Hastelloy C	N10002	...	In liquid	50	...	...	.74 (29)	...	186

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy C	N10002	...	In liquid	65	...	...	.19 (7.6)	...	186
Hastelloy C	N10002	...	In vapor, nitrogen purged	50	...	...	.6 (24)	...	186
Hastelloy C	N10002	...	In vapor, nitrogen purged	65	...	...	.24 (9.6)	...	186
Hastelloy D	...	...	...	25	23	5 d	.15 (6)	...	186
Hastelloy D	...	...	...	40	23	5 d	.025 (1)	...	186
Hastelloy D	...	...	...	40	54 (130)	5 d	.07 (2.6)	...	186
Hastelloy D	...	...	...	45	23	5 d	0.1. (4)	...	186
Hastelloy D	...	...	...	5	23	5 d	.025 (1)	...	186
Hastelloy D	...	...	...	60	23	5 d	0.06 (2.4)	...	186
Hastelloy F	N06001	...	...	25	23	5 d	0.30 (12)	...	186
Hastelloy F	N06001	...	...	45	23	5 d	0.38 (15)	...	186
Hastelloy F	N06001	...	...	5	23	5 d	0.05 (2.0)	...	186
Hastelloy G-30	N06030	...	Liquid	40	50 (122)	30 d	0.32 (13)	...	225
Hastelloy G-30	N06030	...	Solution not deaerated	2	70 (160)	4 h	.25 (10)	...	186
Hastelloy G-30	N06030	...	Solution not deaerated	5	70 (160)	4 h	.76 (30)	...	186
Hastelloy G-30	N06030	...	Vapor	40	50 (122)	30 d	1.08 (43)	...	225
Illium 98	...	...	In liquid	50	...	...	.22 (8.7)	...	186
Illium 98	...	...	In liquid	50	...	...	0.2 (8.4)	...	186
Illium 98	...	...	In vapor, nitrogen purged	65	...	...	.08 (3.2)	...	186
Illium 98	...	...	In vapor, nitrogen purged	65	...	...	0.02 (0.84)	...	186
Incoloy alloy 825	N08825	...	...	20	102 (215)	3 d	1.04 (41)	...	186
Incoloy alloy 825	N08825	...	...	38	Boiling	4 d	.25 (10)	...	186
Incoloy alloy 825	N08825	...	...	48	Boiling	4 d	.23 (9)	...	186
Incoloy alloy 825	N08825	...	...	50	60 (140)	35 d	0.05 (2)	...	186
Incoloy alloy 825	N08825	...	...	65	60 (140)	35 d	.13 (5)	...	186
Incoloy alloy 825	N08825	...	...	70	21 (70)	42 d	.35 (14)	...	186
Incoloy alloy 825	N08825	...	...	70	60 (140)	35 d	.13 (5)	...	186
Inconel 600	N06600	...	Anhydrous gas	...	500 (930)	...	1.5 (60)	...	186
Inconel 600	N06600	...	Anhydrous gas	...	600 (1110)	...	1.5 (60)	...	186
Inconel 600	N06600	...	Anhydrous	...	25-40 (80-100)	...	.067 (2.6)	...	186
Inconel 600	N06600	...	Gaseous	...	...	...	.018 (0.7)	...	186
Inconel 617	N06617	...	Liquid. Average of two tests	10	80 (175)	...	3.20 (126)	...	44
Inconel 617	N06617	...	Liquid. Average of two tests	20	80 (175)	...	7.67 (302)	...	44
Inconel 617	N06617	...	Liquid. Average of two tests	30	80 (175)	...	10.06 (396)	...	44
Inconel 617	N06617	...	Liquid. Average of two tests	40	80 (175)	...	10.77 (424)	...	44
Inconel 617	N06617	...	Liquid. Average of two tests	48	80 (175)	...	10.87 (428)	...	44
Inconel 617	N06617	...	Vapor. Average of two tests	10	80 (175)	...	1.12 (44)	...	44
Inconel 617	N06617	...	Vapor. Average of two tests	20	80 (175)	...	0.81 (32)	...	44
Inconel 617	N06617	...	Vapor. Average of two tests	30	80 (175)	...	2.08 (82)	...	44
Inconel 617	N06617	...	Vapor. Average of two tests	40	80 (175)	...	2.16 (85)	...	44
Inconel 617	N06617	...	Vapor. Average of two tests	48	80 (175)	...	2.64 (104)	...	44
Monel 400	N04400	...	Anhydrous gas	...	500 (930)	...	1.2 (48)	...	186
Monel 400	N04400	...	Anhydrous gas	...	550 (1020)	...	1.2 (48)	...	186
Monel 400	N04400	...	Anhydrous gas	...	600 (1110)	...	1.8 (72)	...	186
Monel 400	N04400	...	Anhydrous	...	15-25 (60-80)	...	.08 (3.2)	...	186
Monel 400	N04400	...	Anhydrous	...	25-40 (80-100)	...	.02 (0.9)	...	186
Monel 400	N04400	...	Anhydrous	...	40-95 (100-200)	...	.12 (4.7)	...	186
Monel 400	N04400	...	Gaseous	...	...	...	.33 (13)	...	186
Monel 400	N04400	...	In liquid	50	...	...	.46 (18)	...	186
Monel 400	N04400	...	In liquid	65	...	...	.13 (4.8)	...	186
Monel 400	N04400	...	In liquid	70	...	...	.14 (5.4)	...	186
Monel 400	N04400	...	In vapor, nitrogen purged	50	...	...	.12 (4.7)	...	186
Monel 400	N04400	...	In vapor, nitrogen purged	65	...	...	.06 (2.3)	...	186
Monel 400	N04400	...	In vapor, nitrogen purged	70	...	...	.05 (2.0)	...	186

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel K-500	N05500	...	Gaseous	...	...	...	0.4 (16)	...	186
Ni-30-19P	...	Amorphous	...	47	110	7 d	10 (400)	...	189
Ni-30-19P	...	Amorphous	...	47	30	7 d	.03 (1.2)	...	189
Ni-30-19P	...	Amorphous	...	47	60	7 d	.15 (6)	...	189
Ni-30-19P	...	Amorphous	...	47	90	7 d	5 (200)	...	189
Nickel 200	N02200	...	Anhydrous gas	...	600 (1110)	...	0.9 (36)	...	186
Nickel 200	N02200	...	Anhydrous gas	100	500 (930)	4 h	0.9 (36)	...	186
Nickel 200	N02200	...	Anhydrous	...	15-25 (60-80)	...	.06 (2.5)	...	186
Nickel 200	N02200	...	Anhydrous	...	70 (160)	...	.12 (4.6)	...	186
Nickel 200	N02200	...	Gaseous	...	...	...	.23 (9)	...	186
Nickel 200	N02200	...	Solution not deaerated	5	70 (160)	4 h	.46 (18)	...	186
Nickel 201	N02201	...	Gaseous	...	...	...	.36 (14)	...	186
Sanicro 28	N08028	...	...	...	80 (176)	...	1.28 (51)	...	212
Refractory metals and alloys									
44Co-31Cr-13W	...	Cast specimen	Average of five 24-h periods	5	Room	...	1.47 (59)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimen	Average of five 24-h periods	5	Room	...	1.37 (55)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimen	Average of five 24-h periods	5	Room	...	1.37 (55)	...	53
50Co-20Cr-15W-10Ni	...	...	...	5	Room	...	0.125 (0.5)	...	53
50Co-20Cr-15W-10Ni	...	Cast specimen	Average of five 24-h periods	5	Room	...	0.125 (5)	...	53
53Co-30Cr-4.5W	...	Cast specimen	Average of five 24-h periods	5	Room	...	1.3 (52)	...	53
53Co-30Cr-4.5W	...	Cast specimen	Average of five 24-h periods	5	Room	...	1.3 (52)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimen	Average of five 24-h periods	5	Room	...	0.8 (32)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast specimen	Average of five 24-h periods	5	Room	...	0.8 (32)	...	53
Cobalt	...	...	Static	50	25 (77)	...	0.72 (29)	...	54
Cobalt	...	...	Static	Conc	25 (77)	...	0.4 (16)	...	54
Cr-Phos alloy	...	Argon-arc melted	0.8% P	47	30	7 d	0.1 (4)	...	191
Cr-Phos alloy	...	Argon-arc melted	1.0% P	47	30	7 d	0.15 (6)	...	191
Cr-Phos alloy	...	Argon-arc melted	2.0% P	47	30	7 d	0.18 (7)	...	191
Cr-Phos alloy	...	Argon-arc melted	5.0% P	47	30	7 d	0.18 (7)	...	191
Haynes No.25	R30605	12-gage, solution heat-treated sheet	...	5	Room	...	0.13 (5.0)	...	68
Haynes No.25	R30605	12-gage, solution heat-treated sheet	...	25	Room	...	0.30 (12)	...	68
Haynes No.25	R30605	12-gage, solution heat-treated sheet	...	45	Room	...	0.51 (20)	...	68
Multimet	R30155	12-gage, solution heat-treated sheet	...	5	Room	...	0.13 (5.0)	...	68

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	12-gage, solution heat-treated sheet	...	25	Room	...	0.94 (37)	...	68
Multimet	R30155	12-gage, solution heat-treated sheet	...	45	Room	...	1.32 (52)	...	68
Tantalum	R05210	...	...	40	25 (76)	3 h	Poor	...	42
Titanium	...	...	...	1	26 (79)	...	127 (5080)	...	90
Titanium	...	...	Anhydrous	100	Room	...	1.27 (50.8) max	...	90
Zr702	R60702	...	...	0-100	Room	...	1.3 (50) min	...	15
Stainless steels									
20 Cb-3	N08020	...	...	...	80 (176)	...	29 (1164)	...	212
20Cb-3	N08020	...	...	70	21 (70)	42 d	.38 (15)	...	186
301	S30100	...	...	40	20 (68)	...	Poor	...	253
302	S30200	...	...	40	20 (68)	...	Poor	...	253
303	S30300	...	...	40	20 (68)	...	Poor	...	253
303	S30300	...	...	40	20 (68)	...	Poor	...	253
304	S30400	...	...	.15	60 (140)	10 d	1.2 (47)	...	186
304	S30400	...	...	0.05	60 (140)	10 d	0.3 (12)	...	186
304	S30400	...	...	0.1	60 (140)	10 d	.64 (25)	...	186
304	S30400	...	...	0.2	60 (140)	10 d	1.6 (62)	...	186
304	S30400	...	...	10	16 (60)	30 d	.01 (.4)	...	186
304	S30400	...	...	40	20 (68)	...	Poor	...	253
304	S30400	...	...	90	21 (70)	1 d	.76 (30)	...	186
304	S30400	...	...	90	4 (40)	0.2 d	.9 (35)	...	186
304	S30400	...	Anhydrous gas	...	600 (1110)	...	13.4 (528)	...	186
304	S30400	...	Anhydrous	...	15-25 (60-80)	...	.16 (6.2)	...	186
304	S30400	...	Anhydrous	...	25-40 (80-100)	...	.12 (4.8)	...	186
304	S30400	...	Anhydrous	...	80-90 (180-190)	...	.06 (2.4)	...	186
304	S30400	...	Chemical processing; field or plant test; no aeration; no agitation. Plus 1.5-2.5% hydrofluosilicic acid, 1.2% sulfuric acid, 0.01-0.03% iron ion	60-65	-1.1-26 (30-80)	28 d	Poor	...	89
304	S30400	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 17 vol% water vapor, 10 vol% sulfuric acid, 1 vol% fluosilicic acid, vapors and condensate	72 vol%	176 (350)	14 d	Poor	...	89
304	S30400	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 0.2% hydrofluosilicic acid	12	83 (182)	7.2 d	4.0 (160)	Severe pitting	89
304	S30400	...	Chemical processing; field or plant test; strong aeration; rapid agitation. Plus 30% air, 12% water, 7% sulfuric acid, 1% silicon tetrafluoride vapors	50	176 (350)	7 d	3.3 (133)	...	89
304	S30400	...	Chemical processing; field or plant test; strong aeration; rapid agitation. Plus 30% air, 12% water, 7% sulfuric acid, 1% silicon tetrafluoride vapors	50	176 (350)	7 d	3.5 (139)	...	89

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Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Glass processing; field or plant test; no aeration; slight to moderate agitation, with carbon over the standard maximum. Glass-etching solution, plus 9% ammonium bifluoride, water during 200 h and 49% hydrofluoric acid, 15% ammonium bifluoride, sulfuric acid, water during 24 h	37	75 (167)	9.3 d	Poor	...	89
304	S30400	...	Glass processing; field or plant test; no aeration; slight to moderate agitation, with carbon over the standard maximum. Glass-etching solution, plus 14% ammonium bifluoride, water during 72h and 40% hydrofluoric acid, plus 15% ammonium bifluoride, 4% ammonium fluosilicate, water during 176 h	29	60 (140)	10.3 d	3.5 (140)	...	89
304	S30400	...	Petroleum processing; field or plant test; no aeration, no agitation. Plus 71% organic fluorides, 19% benzene	6	135 (275)	226 d	0.3 (1.2)	Severe pitting	89
304	S30400	...	Petroleum processing; field or plant test; no aeration; no agitation. Plus isobutane, regeneration-tower top, vapors	~46.5	98-104 (210-220)	49 d	1.6 (63)	Severe pitting	89
304	S30400	...	Petroleum processing; field or plant test; no aeration; no agitation. Plus isobutane, regeneration-tower top, vapors	~46.5	98-104 (210-220)	49 d	Poor	Severe pitting	89
304	S30400	...	Velocity = .14 to .43 m/s	90	21 (70)	1 d	.28 (11)	...	186
304L	S30403	...	...	40	20 (68)	...	Poor	...	253
304LN	S30453	...	...	40	20 (68)	...	Poor	...	253
309Cb	S30940	...	Anhydrous gas	...	500 (930)	...	5.8 (228)	...	186
309Cb	S30940	...	Anhydrous gas	...	550 (1020)	...	42.7 (1680)	...	186
309Cb	S30940	...	Anhydrous gas	...	600 (1110)	...	168 (6600)	...	186
309Cb	S34700	...	...	.05	60 (140)	10 d	.25 (10)	...	186
309Cb	S34700	...	...	.1	60 (140)	10 d	.69 (27)	...	186
309Cb	S34700	...	...	.15	60 (140)	10 d	1.1 (44)	...	186
309Cb	S34700	...	...	.2	60 (140)	10 d	1.4 (54)	...	186
310	S31000	...	Anhydrous gas	...	500 (930)	...	12.2 (480)	...	186
310	S31000	...	Anhydrous gas	...	550 (1020)	...	101 (3960)	...	186
310	S31000	...	Anhydrous gas	...	600 (1110)	...	305 (12000)	...	186
316	S31600	...	...	10	16 (60)	30 d	.002 (0.1) max	...	186
316	S31600	...	...	38	110 (230)	2 d	51 (2000)	...	186
316	S31600	...	...	40	20 (68)	...	Poor	...	253
316	S31600	...	...	70	21 (70)	42 d	1.24 (49)	...	186
316	S31600	...	...	98	34-44 (95-110)	3.5 d	.05 (2)	...	186
316	S31600	...	Chemical processing; field or plant test; no aeration; no agitation. Plus 1.5-2.5% hydrofluosilicic acid, 1.2% sulfuric acid, 0.01-0.03% iron ion	60-65	-1.1-26 (30-80)	28 d	Poor	...	89
316	S31600	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 17 vol% water vapor, 10 vol% sulfuric acid, 1 vol% fluosilicic acid, vapors and condensate	72 vol%	176 (350)	14 d	6 (240)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 17 vol% water vapor, 10 vol% sulfuric acid, 1 vol% fluosilicic acid, vapors and condensate	72 vol%	176 (350)	14 d	10 (380) min	...	89
316	S31600	...	Chemical processing; field or plant test; no aeration; rapid agitation. Plus 0.2% hydrofluosilicic acid	12	83 (182)	7.2 d	18 (700)	Severe pitting	89
316	S31600	...	Chemical processing; field or plant test; strong aeration; rapid agitation. Plus 30% air, 12% water, 7% sulfuric acid, 1% silicon tetrafluoride vapors	50	176 (350)	7 d	2.6 (103)	...	89
316	S31600	...	Chemical processing; field or plant test; strong aeration; rapid agitation. Plus 30% air, 12% water, 7% sulfuric acid, 1% silicon tetrafluoride vapors	50	176 (350)	7 d	2.8 (113)	...	89
316	S31600	...	Glass processing; field or plant test. Plus 50% sulfuric acid	50	Room to 60 (140)	4 d	2.5 (100)	Severe pitting	89
316	S31600	...	Glass processing; field or plant test; no aeration; slight to moderate agitation. Glass-etching solution, plus 9% ammonium bifluoride, water during 200 h and 49% hydrofluoric acid, 15% ammonium bifluoride, sulfuric acid, water during 24 h	37	75 (167)	9.3 d	Poor	...	89
316	S31600	...	Glass processing; field or plant test; no aeration; slight to moderate agitation. Glass-etching solution, plus 14% ammonium bifluoride, water during 72 h and 40% hydrofluoric acid, plus 15% ammonium bifluoride, 4% ammonium fluosilicate, water during 176 h	29	60 (140)	10.3 d	2.5 (100)	...	89
316	S31600	...	Mining; field or plant test; no aeration; slight to moderate agitation. Commercial grade	70	21 (70)	42 d	12 (490)	...	89
316	S31600	...	Petroleum processing; field or plant test; no aeration, no agitation. Plus 71% organic fluorides, 19% benzene	6	135 (275)	226 d	0.3 (12)	Moderate pitting	89
316	S31600	...	Petroleum processing; field or plant test; no aeration; no agitation. Plus isobutane, regeneration-tower top, vapors	~46.5	98-104 (210-220)	49 d	0.03 (1)	Severe pitting	89
316	S31600	...	Petroleum processing; field or plant test; no aeration; no agitation	38	110 230	2 d	50 2000	Severe pitting	89
316F	S31620	...	...	40	20 (68)	...	Poor	...	253
316L	S31603	...	...	40	20 (68)	...	Poor	...	253
316L	S31603	...	Plus 10% HNO_3	3	80 (176)	...	43 (1700)	...	212
316LN	S31653	...	...	40	20 (68)	...	Poor	...	253
316Ti	S31635	...	...	40	20 (68)	...	Poor	...	253
317L	S31703	...	...	40	20 (68)	...	Poor	...	253
317LN	S31725	...	...	40	20 (68)	...	Poor	...	253
321	S32100	...	...	40	20 (68)	...	Poor	...	253
329	S32900	...	...	40	20 (68)	...	Poor	...	253
347	S34700	...	...	40	20 (68)	...	Poor	...	253
347	S34700	...	Anhydrous gas	...	500 (930)	...	183 (7200)	...	186

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrofluoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	Anhydrous gas	...	550 (1020)	...	457 (18000)	...	186
347	S34700	...	Anhydrous gas	...	600 (1110)	...	177 (6960)	...	186
403	S40300	...	...	40	20 (68)	...	Poor	...	253
405	S40500	...	...	40	20 (68)	...	Poor	...	253
409	S40900	...	...	40	20 (68)	...	Poor	...	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	40	20 (68)	...	Poor	...	253
416	S41600	...	...	40	20 (68)	...	Poor	...	253
420	S42000	...	...	40	20 (68)	...	Poor	...	253
430	S43000	...	...	40	20 (68)	...	Poor	...	253
430	S43000	...	Anhydrous gas	...	500 (930)	...	1.5 (60)	...	186
430	S43000	...	Anhydrous gas	...	550 (1020)	...	9.1 (360)	...	186
430	S43000	...	Anhydrous gas	...	600 (1110)	...	11.6 (456)	...	186
434	S43400	...	...	40	20 (68)	...	Poor	...	253
Alloy 904L	N08904	...	...	...	80 (176)	...	4.0 (160)	...	212

Corrosion Behavior of Various Metals and Alloys in Hydrogen Fluoride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Dry gaseous	...	100 (212)	...	Good	...	253
302	S30200	...	Dry gaseous	...	100 (212)	...	Good	...	253
303	S30300	...	Dry gaseous	...	100 (212)	...	Poor	...	253
303	S30300	...	Dry gaseous	...	100 (212)	...	Good	...	253
304	S30400	...	Dry gaseous	...	100 (212)	...	Good	...	253
304L	S30403	...	Dry gaseous	...	100 (212)	...	Good	...	253
304LN	S30453	...	Dry gaseous	...	100 (212)	...	Good	...	253
316	S31600	...	Dry gaseous	...	100 (212)	...	Good	...	253
316F	S31620	...	Dry gaseous	...	100 (212)	...	Good	...	253
316L	S31603	...	Dry gaseous	...	100 (212)	...	Good	...	253
316LN	S31653	...	Dry gaseous	...	100 (212)	...	Good	...	253
316Ti	S31635	...	Dry gaseous	...	100 (212)	...	Good	...	253
317L	S31703	...	Dry gaseous	...	100 (212)	...	Good	...	253
317LN	S31725	...	Dry gaseous	...	100 (212)	...	Good	...	253
321	S32100	...	Dry gaseous	...	100 (212)	...	Good	...	253
347	S34700	...	Dry gaseous	...	100 (212)	...	Good	...	253
329	S32900	...	Dry gaseous	...	100 (212)	...	Good	...	253
F51	S31803	...	Dry gaseous	...	100 (212)	...	Good	...	253
405	S40500	...	Dry gaseous	...	100 (212)	...	Poor	...	253
409	S40900	...	Dry gaseous	...	100 (212)	...	Poor	...	253
430	S43000	...	Dry gaseous	...	100 (212)	...	Poor	...	253
434	S43400	...	Dry gaseous	...	100 (212)	...	Good	...	253
403	S40300	...	Dry gaseous	...	100 (212)	...	Poor	...	253
410	S41000	...	Dry gaseous	...	100 (212)	...	Poor	...	253
416	S41600	...	Dry gaseous	...	100 (212)	...	Poor	...	253
420	S42000	...	Dry gaseous	...	100 (212)	...	Poor	...	253

Corrosion of Hastelloy Alloys in Aqueous Hydrofluoric Acid

Concentration HF, %	Temperature °C (°F)	Corrosion rate: Hastelloy B mm/yr	Hastelloy B mils/yr	Hastelloy C mm/yr	Hastelloy C mils/yr	Hastelloy D mm/yr	Hastelloy D mils/yr	Hastelloy F mm/yr	Hastelloy F mils/yr
5	Room	0.1	4	0.025	1	0.025	1	0.05	2
25	Room	0.13	5	0.13	5	0.15	6	0.3	12
40	Room	0.07	2.6	0.074	2.9	0.025	1	...	...
40	54 (130)	0.025	1	0.025	10	0.07	2.6	...	...
45	Room	0.076	3	0.15	6	0.1	4	0.38	15
50	Boiling (95 °C, or 205 °F)	...	...	4.6	180	...	...	...	...
60	Room	0.04	1.6	0.09	3.6	0.06	2.4	...	...
65	Boiling (70 °C, or 160 °F)	...	...	0.43	17	...	...	...	...
98	34–44 (95–110)	0.1	4	0.025	1	...	...	...	...

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Various Nickel-Base Alloys in Hydrofluoric Acid

Alloy	Corrosion rate, mm/yr (mils/yr): 2% HF, 70 °C (160 °F)	2% HF, Boiling	5% HF, 70 °C (160 °F)	5% HF, Boiling
C-276	0.24 (9.5)	0.076 (3)	0.25 (10)	0.1 (4)
C-22	0.23 (9.4)	0.94 (37)	0.34 (13.5)	0.84 (33)
625	0.5 (20)	...	0.4 (16)	...
C-4	0.43 (17)	...	0.38 (15)	...
200	...	...	0.46 (18)	...
600	...	...	0.23 (9)	...
B-2	...	...	0.38 (15)	...
G-3	...	...	0.5 (20)	...
G-30	(10)	...	0.76 (30)	...

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Effect of Aeration on Corrosion of Two Nickel-Base Alloys in 70% Hydrofluoric Acid

Alloy	Corrosion rate: Nitrogen blanket mm/yr	Nitrogen blanket mils/yr	Oxygen blanket mm/yr	Oxygen blanket mils/yr
C-276	0.008	0.3	0.94	37
400	0.013	0.5	0.58	23

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Metals and Alloys in Hydrofluoric Acid Gas

Alloy	Corrosion rate mm/yr	Corrosion rate mils/yr
Hastelloy C	0.008	0.3
Inconel 600	0.018	0.7
Hastelloy B	0.05	2
Nickel 200	0.23	9
Nickel 201	0.36	14
Monel 400	0.33	13
Monel K-500	0.4	16
70–30 copper-nickel	0.4	16

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Effect of Oxygen on Corrosion of Alloy 400 in Hydrofluoric Acid Solutions

Concentration of oxygen in purge gas, ppm	Corrosion rate — Boiling (112 °C, or 234 °F) 38% HF — Liquid phase mm/yr	mils/yr	Vapor phase mm/yr	mils/yr	Boiling (108 °C, or 226 °F) 48% HF — Liquid phase mm/yr	mils/yr	Vapor phase mm/yr	mils/yr
<5	0.24	9.5	0.17	6.8	0.28	11	0.076	3
<500	0.43	17	0.3	12	0.56	22	0.1	4
1500	0.79	31	1.24	49	0.7	28	0.61	24
2500	0.74	29	0.46	18	0.69	27	0.23	9
3500	0.86	34	1.37	54	0.86	34	0.74	29
4700	1.3	53	2.7	107	1.1	43	2.1	83
10 000	1.2	46	0.64	25	1.2	48	1.9	75

Source: Inco Alloys International.

Corrosion of Metals and Alloys by Gaseous Anhydrous Hydrofluoric Acid at Elevated Temperatures

Metal	Corrosion rate at temperature, °C (°F) — 500 (930) mm/yr	mils/yr	550 (1020) mm/yr	mils/yr	600 (1110) mm/yr	mils/yr
Nickel 200	0.9	36	...	...	0.9	36
Monel 400	1.2	48	1.2	48	1.8	72
Copper	1.5	60	...	...	1.2	48
Inconel 600	1.5	60	...	...	1.5	60
Aluminum alloy 1100	4.9	192	...	...	14.6	576
Magnesium G	13.8	542	...	...	...	...
1020 steel	15.5	612	14.6	576	7.6	300
Type 430 stainless steel	1.5	60	9.1	360	11.6	456
Type 304 stainless steel	...	...	...	...	13.4	528
Type 347 stainless steel	183	7200	457	18 000	177	6960
Type 309Cb stainless steel	5.8	228	42.7	1680	168	6600
Type 310 stainless steel	12.2	480	100.6	3960	305	12 000

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Nickel Stainless Steels and Chromium-Nickel-Molybdenum-Iron Alloys in Aqueous Hydrofluoric Acid

Concentration HF, %	Temperature °C	°F	Test duration, days	Corrosion rate — Type 304 mm/yr	mils/yr	Type 316 mm/yr	mils/yr	Type 309Cb mm/yr	mils/yr	Alloy 20Cb-3 mm/yr	mils/yr	Incoloy 825 mm/yr	mils/yr
0.05	60	140	10	0.3	12	...	...	0.25	10	...	...	...	...
0.1	60	140	10	0.64	25	...	...	0.69	27	...	...	...	...
0.15	60	140	10	1.2	47	...	...	1.1	44	...	...	...	...
0.2	60	140	10	1.6	62	...	...	1.4	54	...	...	...	...
10	16	60	30	0.01	0.4	<0.002	<0.1	...	...	...	...	...	...
20	102	215	3	...	...	...	...	...	...	...	...	1.04	41
38	110	230	2	...	...	51	2000	...	...	...	...	...	...
38	Boiling		4	...	...	...	...	...	...	...	...	0.25	10
48	Boiling		4	...	...	...	...	...	...	...	...	0.23	9
50	60	140	35	...	...	...	...	...	...	...	...	0.05	2
65	60	140	35	...	...	...	...	...	...	...	...	0.13	5
70	60	140	35	...	...	...	...	...	...	...	...	0.13	5
70	21	70	42	...	...	1.24	49	...	...	0.38	15	0.35	14
90	4	40	0.2	0.9	35	...	...	...	...	...	...	...	...
90	21	70	1	0.76	30	...	...	...	...	...	...	...	...
90	21	70	1	0.28	11(a)	...	...	...	...	...	...	...	...
98	34–44	95–110	3.5	...	...	0.05	2	...	...	...	...	...	...

(a) Velocity: 0.14 to 0.43 m/s (0.4 to 1.4 ft/s)

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Metals and Alloys in Anhydrous Hydrogen Fluoride

Metal	Corrosion rate at temperature, °C (°F)											
	15–25 (60–80)		25–40 (80–100)		40–95 (100–200)		55 (130)		70 (160)		80–90 (180–190)	
	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr
Carbon steel	0.07	2.8	0.16	6.2	...	...	0.35	14	...	...	2.3	89
Low-alloy steel	0.15	6	0.14	5.9	...	...	...	...	...	...	2	78
Austenitic stainless steel	0.16	6.2	0.12	4.8	...	...	...	...	...	...	0.06	2.4
Monel 400	0.08	3.2	0.02	0.9	0.12	4.7	...	...	...	...	...	...
Copper	0.33	12.9	...	...	...	...	...	...	...	...	...	...
Nickel 200	0.06	2.5	...	...	...	...	...	...	0.12	4.6	...	...
70–30 copper-nickel	...	...	0.05	2	...	...	0.008	0.3	...	...	0.25	10
80–20 copper-nickel	...	...	0.13	5.2	...	...	...	...	...	...	...	...
Red brass	0.76	30	0.4	16	...	...	...	...	...	...	1.3	50
Admiralty brass	0.25	10	0.33	12.8	...	...	0.01	0.4	...	...	0.5	20
Aluminum-bronze	0.37	14.4	...	...	...	...	...	...	...	...	...	...
Phosphorus-bronze	0.5	20	0.48	18.8	...	...	...	...	...	...	1.5	60
Inconel 600	...	...	0.067	2.6	...	...	...	...	...	...	...	...
Duriron	...	...	1.1	45	...	...	...	...	...	...	...	...
Aluminum	0.52	20.4	...	...	...	...	...	...	...	...	24.8	976
Magnesium	0.13	5.2	0.43	17.1	...	...	nil		...	...	nil	

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Selected Metals and Alloys in Commercial Hydrofluoric Acid Solutions

Metal	Corrosion rate in various acid concentrations											
	50%				65%				70%			
	Liquid		Vapor		Liquid		Vapor		Liquid		Vapor	
	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr	mm/yr	mils/yr
Platinum	nil		nil		nil		nil		...	...	...	...
Silver	0.009	0.36	nil		0.018	0.72	0.0005	0.02	0.018	0.72	0.00025	0.01
Monel 400	0.46	18.12	0.12	4.68	0.13	4.8	0.058	2.28	0.14	5.4	0.05	2.03
Magnesium	0.21	8.4	0.03	1.2	0.058	2.28	0.058	2.28	...	...	...	...
Hastelloy C	0.74	29.3	0.6	24	0.19	7.55	0.24	9.6	...	...	...	...
Illium R	0.22	8.65	0.08	3.23	0.2	8	0.02	0.84	...	...	...	...

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Wrought Copper Alloys in Anhydrous Hydrofluoric Acid

Temperature		Corrosion rate(a)					
		C51000		C44400		C71500	
°C	°F	μm/yr	mils/yr	μm/yr	mils/yr	μm/yr	mils/yr
16–27	60–80	510	20	255	10	180	7
27–38	80–100	480	18.8	480	18.8	...	...
82–88	180–190	1525	60	510	20	255	10

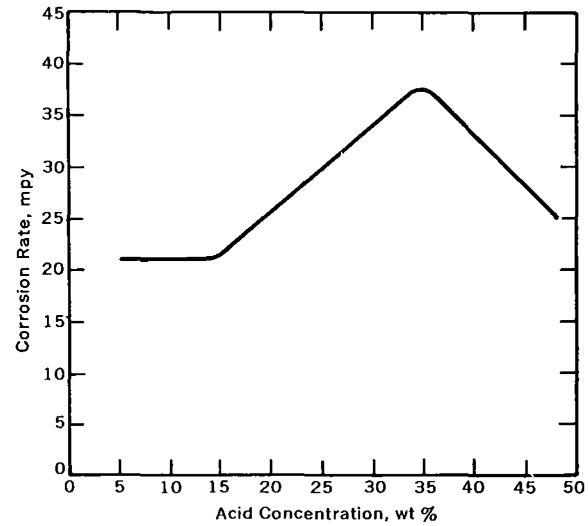
(a) These values are representative of results on copper alloys having high copper content, such as copper, aluminum bronze, silicon bronze, and inhibited admiralty metal. Corrosion rates for C23000 are between those for C44400 and C51000.

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Corrosion of Steel in Hydrofluoric Acid at Ambient Temperature

Concentration of HF, %	Corrosion rate mm/yr	Corrosion rate mils/yr
58	3	120
60	2.53	99.6
61	2.1	81.6
62	1.5	58.8
63	0.24	9.6
64	0.05	2.0
65	0.055	2.2
67.5	0.048	1.9
69.9	0.064	2.5

Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.



Inconel 600. Corrosion rates in hydrofluoric acid at 75 °C (167 °F). Source: Inco Alloys International, 1962.

LIVE GRAPH
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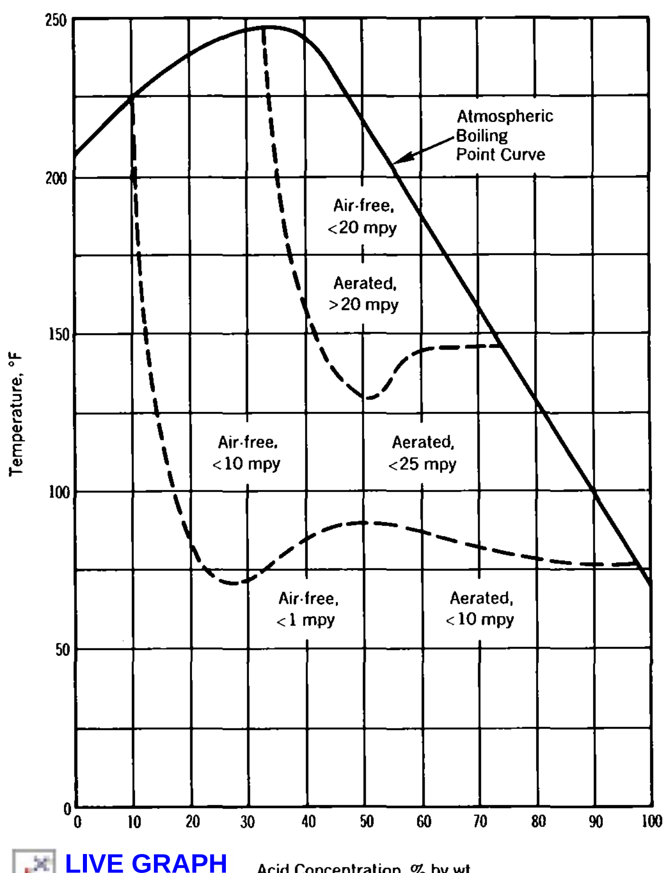
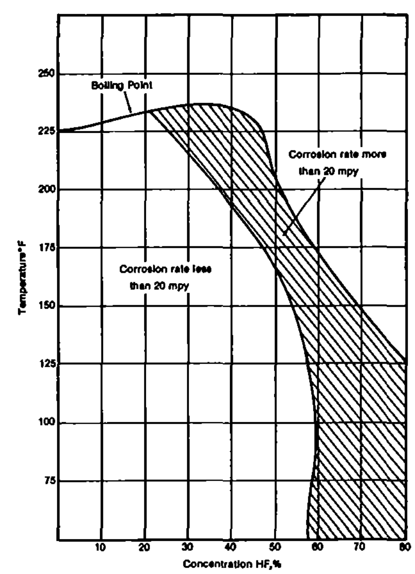


LIVE GRAPH
Click here to view

Monel 400. Isocorrosion charts of Monel 400 in hydrofluoric acid. Source: Inco Alloys International, 1984.



LIVE GRAPH
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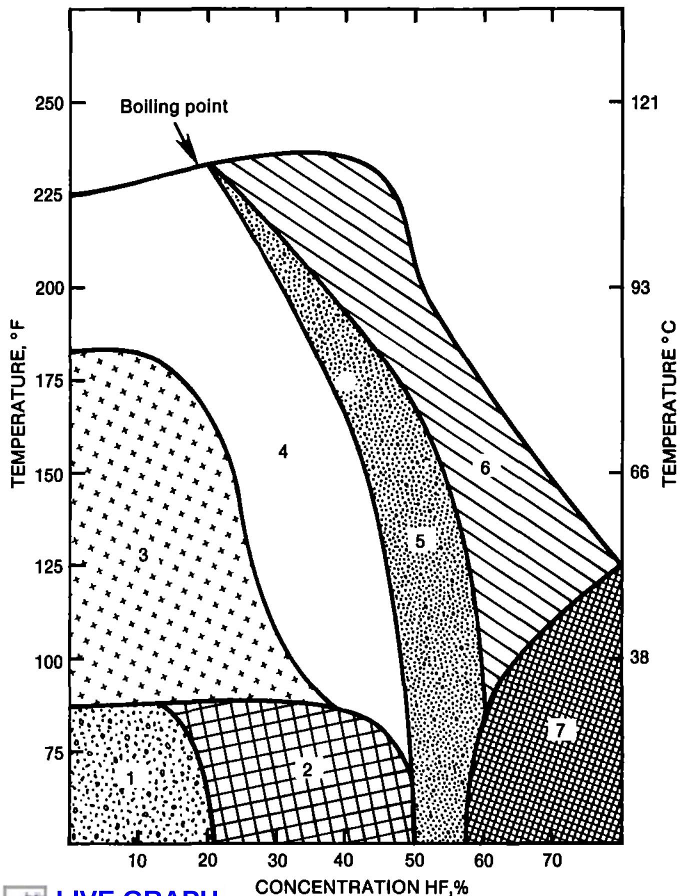
Lead. Corrosion resistance of lead to air-free hydrofluoric acid. Source: *Lead for Corrosion Resistant Applications: A Guide*, Lead Industries Association, Inc. New York.

Hydrofluoric Acid Graph



LIVE GRAPH
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CODE FOR HYDROFLUORIC ACID GRAPH

Materials in shaded zone have reported corrosion rate of >20 mpy

ZONE 1
20Cr 30Ni
25Cr 20 Ni steel
70Cu 30Ni[1]
66Ni 32Cu[1]
54Ni 15Cr 16Mo
Copper[1]
Gold
Lead[1]
Nickel[1]
Nickel cast iron
Platinum Silver

ZONE 2
20Cr 30 Ni
70Cu 30 Ni1
54Ni 15Cr 16Mo
66Ni 32Cu[1]
Copper[1]
Gold
Lead[1]
Nickel[1]
Platinum
Silver

ZONE 3
20Cr 30Ni
70Cu 30Ni[1]
54Ni 15Cr 16Mo
66Ni 32Cu[1]
Copper[1]
Gold
Lead[1]
Platinum
Silver

ZONE 4
70Cu 30Ni[1]
66Ni 32Cu[1]
54Ni 15Cr 16Mo
Gold
Lead[1]
Platinum
Silver

ZONE 5
70Cu 30Ni[1]
6Ni 32Cu[1]
54Ni 15Cr 16Mo
Gold
Lead[1]
Platinum
Silver

ZONE 6
66Ni 32Cu[1]
54Ni 15Cr 16Mo
Gold
Platinum
Silver

ZONE 7
66Ni 32Cu[1]
54Ni 15Cr 16Mo
Gold
Platinum
Silver

[1]No air

Metals and alloys. Corrosion of selected metals and alloys in boiling 48% hydrofluoric acid. Source: T.F. Degnan, "Materials of Construction for Hydrofluoric Acid and Hydrogen Fluoride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986.

Hydrogen

Hydrogen, H_2, is a tasteless, colorless, odorless gas that may be liquified by cooling under pressure. Hydrogen is used in welding, in the production of ammonia, methanol, and other chemicals, for the hydrogenation of oil and coal, and for the reduction of metallic oxide ores. It is obtained by the dissociation of water and as a by-product in the electrolysis of brine solutions. Molecular hydrogen at ambient temperature is relatively innocuous to most metals. However, atomic hydrogen is detrimental to most metals.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon steel. Dry hydrogen gas is often stored and handled successfully in carbon steel equipment at ambient temperature.

Alloy Steels. Alloy steels used in refining petroleum and processing hydrocarbons interact with hydrogen. Prolonged exposure, especially at elevated temperatures, results in loss of ductility and premature failure. Hydrogen attack, which is observed in actual service, is the chemical reaction of hydrogen at elevated temperatures with metal carbides to form methane. The inability of the methane to diffuse out of steel results in blistering and fissuring. The effect of decarburization combined with fissuring results in a loss of strength and ductility.

Aluminum. Hydrogen has been produced and stored in aluminum alloy equipment.

Copper. Copper and its alloys are not attacked by hydrogen unless they contain oxygen. Oxygen-bearing copper heated in hydrogen or hydrogen-bearing gases is invaded by the hydrogen, which reacts with the oxygen to form water. If the temperature is above 375 °C (705 °F), the water is converted to a high-pressure steam, which produces fissures and reduces the ductility of the metal. This condition is known as hydrogen embrittlement, which at any level, can cause catastrophic failure. This reaction is especially important when oxygen-containing copper is bright annealed in reducing atmospheres containing small amounts (1 to 5%) of hydrogen. Annealing of tough pitch coppers, for example C11000, which contains small amounts of copper oxide, in such reducing atmospheres at temperatures above 475 °C (900 °F) may lead to severe embrittlement, especially if annealing times are long. Therefore, tough pitch coppers, which may be welded or brazed, should not be exposed to hydrogen if they will later be used in service at temperatures above 370 °C (700 °F). When copper must be heated in a hydrogen environment, an oxygen-free or deoxidized copper with high residual deoxidizer content, where the oxygen is tied up in complex oxides that do not react appreciably with hydrogen, should be selected. No hydrogen embrittlement problems have been encountered with these materials. Deoxidized coppers with low residual deoxidizer contents, for example C12000, contain copper oxide in smaller amounts than the tough pitch coppers, but are still susceptible to hydrogen embrittlement.

Niobium. Niobium reacts with hydrogen gas above 250 ° (480 °F). At 100 °C (212 °F), niobium is inert in hydrogen.

Silver. Silver can be exposed to hydrogen up to 700 °C (1290 °F).

Tantalum. Tantalum dissolves hydrogen at comparatively low temperatures to a maximum solubility of 50 at.%. Although tantalum generally does not react with molecular hydrogen below 250 °C (480 °F), it can absorb 740 times its own weight at red heat. Tantalum containing more than 150 ppm of hydrogen loses its ductility. When undergoing deformation, tantalum can absorb molecular hydrogen at room temperature. Atomic hydrogen can be absorbed by tantalum even at room temperature. When this material is heated to about 800 °C (1470 °F), or even higher in a vacuum, it loses all its hydrogen. If the metal has not been permanently damaged, it may be restored to its original condition by annealing or degassing at 800 °C (1470 °F). The presence of hydrogen in tantalum increases its hardness and electrical resistivity, whereas it decreases ductility, strength, and density.

Tin. Below its melting point, tin does not react with hydrogen.

Zirconium. Zirconium, which has an oxide film, resists hydrogen absorption up to 760 °C (1400 °F). Zirconium will eventually suffer hydrogen embrittlement in an all-hydrogen environment, with hydrogen absorption beginning at 310 °C (590 °F). Hydrogen may be removed from zirconium by prolonged vacuum annealing at temperatures above 750 °C (1380 °F).

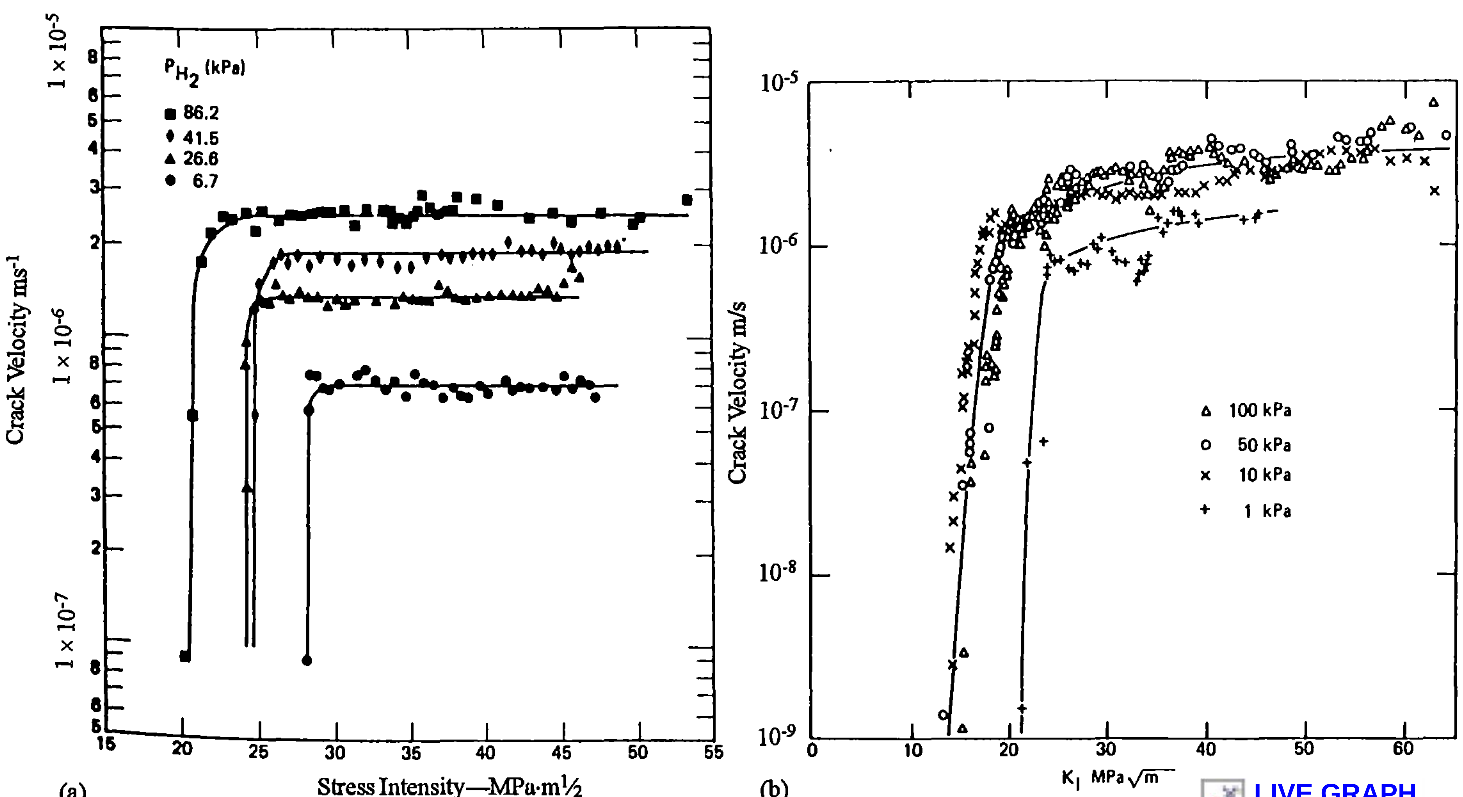
Corrosion Behavior of Various Metals and Alloys in Hydrogen

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5%	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Stainless steels									
304	S30400	...	Petroleum processing; field or pilot plant test; no aeration; rapid agitation. Approx. 20% hydrocarbons, 2-10 grains/100 ft^3 hydrogen sulfide during 1 week, then 2 grains/100 ft^3 average, trace hydrogen chloride	~80	510 (950)	250 d	0.003 (0.1) max	...	89



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(a) Zircaloy-4. Velocity versus stress intensity curves for Zircaloy-4 in hydrogen gas. Ref. 266; (b) Zircaloy-2. Velocity versus stress intensity curves for Zircaloy-2 in hydrogen gas. Ref. 266

Relative Resistance to Hydrogen Embrittlement of Various Alloys in High-Pressure Hydrogen at Room Temperature

Alloy	Stress concentration factor, K_t	Pressure MPa	Pressure ksi	Ratio H_2/He(a)
250 maraging steel	8	69	10	0.12
Type 410 stainless steel	8	69	10	0.22
1042 steel (quenched and tempered)	8	69	10	0.22
17-7PH (TH1050)	8	69	10	0.23
HP9-4-20 alloy steel	8	69	10	0.24
H-11 high-strength steel	8	69	10	0.25
Inconel alloy X-750	6.3	48	7	0.26
René 41	8	69	10	0.27
ED nickel	8	69	10	0.31
4140 steel	8	69	10	0.40
Inconel alloy 718	8	69	10	0.46
MP35N	6.3	69	10	0.50
Type 440C stainless steel	8	69	10	0.50
Ti-6Al-4V (solution treated and aged)	8	69	10	0.58
Monel alloy 400	6.3	48	7	0.65
D-979 stainless steel	6.3	48	7	0.69
Nickel 270	8	69	10	0.70
CG27 stainless steel	6.3	48	7	0.72
ASTM A515, grade 70	8	69	10	0.73
HY-100 steel	8	69	10	0.73
ASTM A372, type IV	8	69	10	0.74
1042 steel (normalized)	8	69	10	0.75
Inconel alloy 625	8	34	5	0.76
ASTM A517, grade F	8	69	10	0.77
ASTM A533, type B	8	69	10	0.78
Waspaloy	6.3	48	7	0.78
Ti-6Al-4V (annealed)	8	69	10	0.79
1020 steel	8	69	10	0.79
HY-80 steel	8	69	10	0.80
Inconel alloy 706	6.3	48	7	0.80
Ti-5Al-2.5Sn	8	69	10	0.81
ARMCO iron	8	69	10	0.86
P/M Inconel alloy 718	6.3	48	7	0.86
Type 304 stainless steel	8	69	10	0.87
Type 321 stainless steel	8	34	5	0.87
Hastelloy alloy X	8	34	5	0.87
Type 305 stainless steel	8	69	10	0.89
Astroloy	8	34	5	0.90
Type 347 stainless steel	8	34	5	0.91
Haynes alloy 188	6.3	48	7	0.92
Type 304N stainless steel	6.3	103	15	0.93
Type 310 stainless steel	8	69	10	0.93
Beryllium-copper	8	69	10	0.93
RA330	6.3	48	7	0.95
A-286	8	69	10	0.97
21-6-9 stainless steel	6.3	48	7	0.97
Aluminum alloy 7075-T73	8	69	10	0.98
Incoloy alloy 802	6.3	48	7	0.99
Aluminum alloy 6061-T6	8	69	10	1.00
Copper (C10100)	8	69	10	1.00
Type 316 stainless steel	8	69	10	1.00
Incoloy alloy 903	8	34	5	1.00

(a) Ratio of notched strength in hydrogen to notched strength in helium

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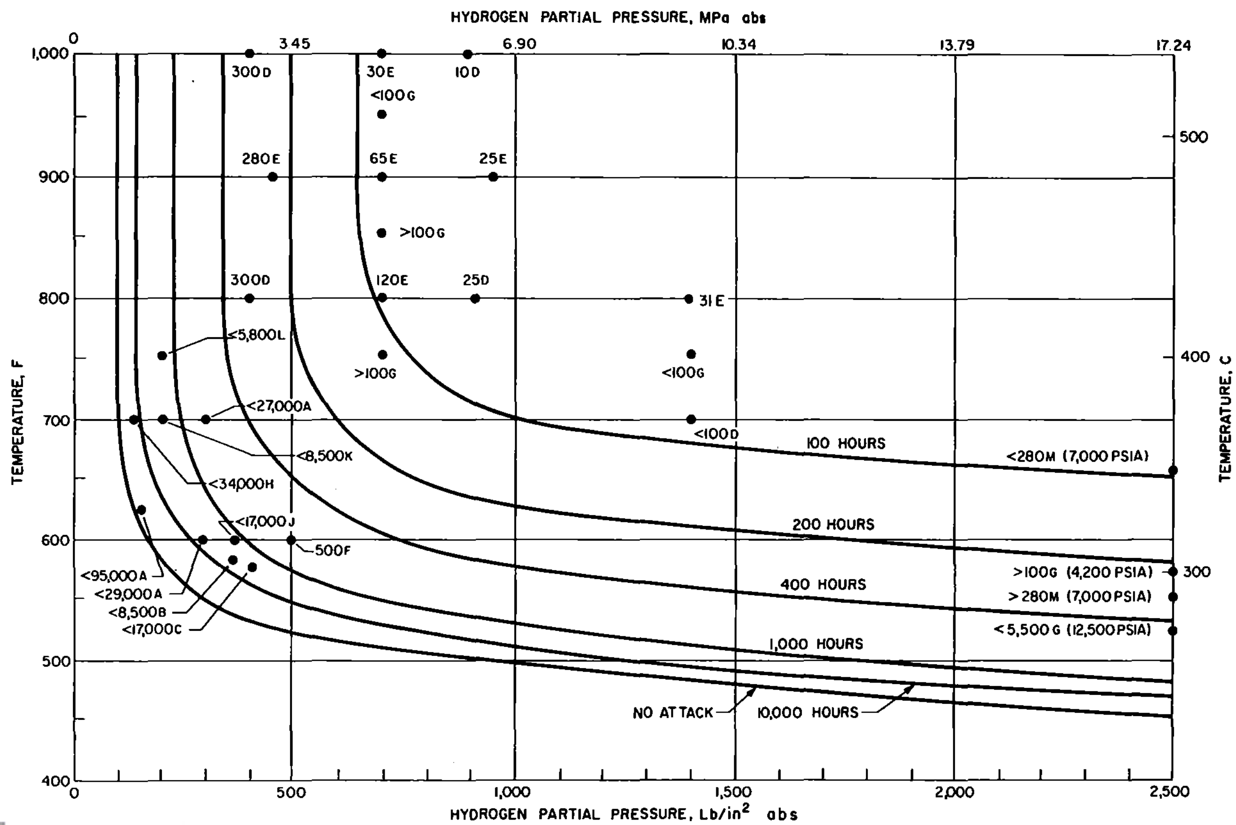

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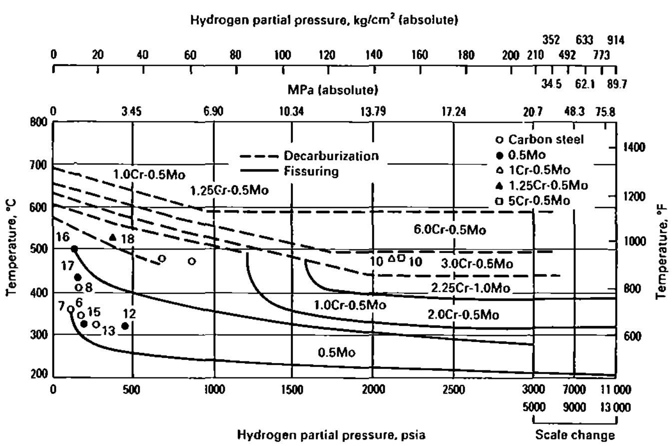
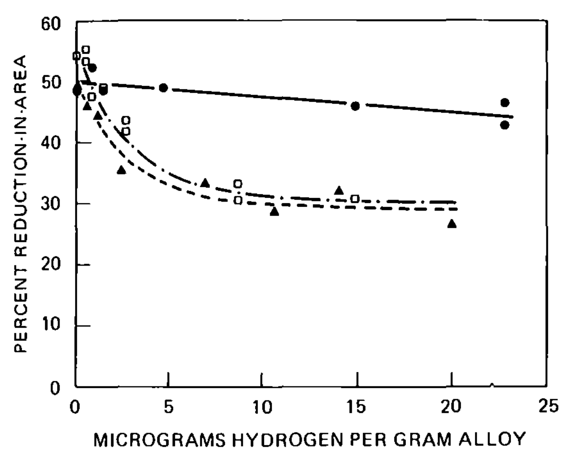
Carbon steel. Time for incipient attack of carbon steel in hydrogen service. Source: *Corrosion Data Survey: Metals Section*, 6th ed., National Association of Corrosion Engineers, Houston, 1985, 174.





Steels. Nelson curve defining safe upper limits for steels in hydrogen service. Source: G.R. Prescott, "Materials Problems in the Hydrogen-Carbon Processing Industries," in *Alloys for the Eighties*, Climax Molybdenum Company, 303-315.

Uranium/niobium alloy. The effect of hydrogen content on the tensile reduction in area of alpha double prime-U-5.7Nb alloy. Closed triangle: 0.06 mm/s crosshead speed, 800 °C anneal. Open square: 0.06 mm/s crosshead speed, 850 °C anneal. Closed circle: 21 mm/s crosshead speed, 800 °C anneal. Source: G.L. Powell and W.G. Northcutt, Jr., "Internal Hydrogen Embrittlement of Uranium-5.7 Niobium Alloy," *Journal of Nuclear Materials*, Vol 132, May 1985, 49.

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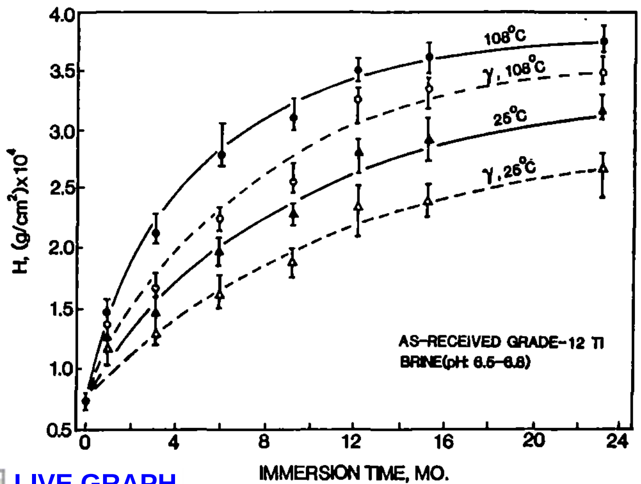

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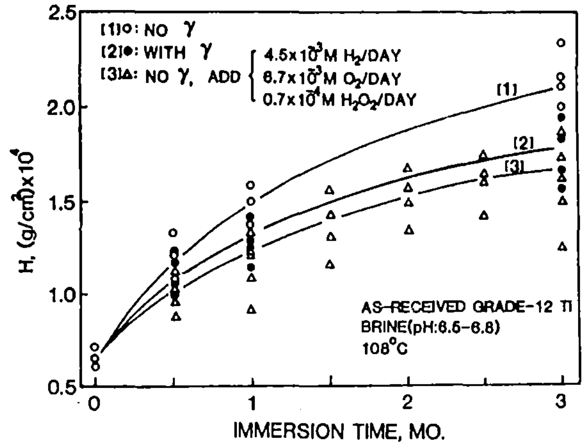
Titanium. Hydrogen take-up by as-received grade 12 titanium in brine vs. immersion time (month) calculated on the basis of metal surface area (gamma signifies gamma radiation). Source: Y.J. Kim, R.A. Oriani, "Corrosion Properties of the Oxide Film Formed on Grade 12 Titanium in Brine Under Gamma Radiation," *Corrosion*, Vol 43, Feb 1987, 87.



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Titanium. Effect of additions of hydrogen, oxygen, and water together on the hydrogen take-up by as-received Grade 12 titanium in brine at 108 °C. Source: Y.J. Kim, R.A. Oriani, "Brine Radiolysis and Its Effects on the Corrosion of Grade 12 Titanium," *Corrosion*, Vol 43, Feb 1987, 92-97.

Hydrogen Chloride

Hydrogen chloride, HCl, is a fuming, highly toxic gas that is soluble in water, alcohol, and ether. It is used in polymerization, isomerization, and the synthesis of vinyl chloride and alkyl chloride.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. Hydrogen chloride and chlorine gas may be handled in cast iron. Unalloyed cast iron can be used in dry hydrogen chloride up to 205 °C (400 °F), but if moisture is present, unalloyed cast iron is unacceptable at any temperature.

Aluminum. Hydrogen chloride corrodes aluminum alloys at all temperatures, but the rate increases as the temperature increases. Dry hydrogen chloride has been handled in aluminum equipment.

Gold. Gold is resistant to hydrogen chloride up to 870 °C (1600 °F).

Platinum. Platinum is resistant to dry hydrogen chloride even at elevated temperatures.

Nickel. Dry hydrogen chloride is resisted by Nickel 200 at low temperatures. Nickel 201 and Inconel alloy 600 are the preferred alloys for use at elevated temperatures. For example, Nickel 201 had a corrosion rate in dry hydrogen chloride of about 0.075 mm/yr (3 mil/yr) in a 500-h laboratory test at 499 °C (930 °F). Inconel alloy 600 corrodes in wet hydrogen chloride, although the corrosion rates are the same as those for dry hydrogen chloride at temperatures above the dew point. The metal corrodes in hydrogen chloride to form a film of metal chloride. This film is protective at intermediate temperatures, but the film volatilizes at higher temperatures and the surface again corrodes to form another film.

Titanium. Titanium alloys have a protective oxide film that resists attack by dry hydrogen chloride at temperatures above 150 °C (300 °F).

Corrosion Behavior of Various Metals and Alloys in Hydrogen Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	Dry	...	870 (1600)	...	0.05 (2) max	...	8

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Gold	P00016	...	Dry	...	870 (1600)	...	0.05 (2) max	...	8
Platinum	P04995	...	Dry. Corrosion rate is increased by the presence of steam or oxidizing agents	...	1200 (2190)	...	0.1 (4) max	...	6
Silver	P07010	...	Dry. Protected by a layer of silver chloride that forms rapidly on the surface	...	430 (805)	...	0.05 (2) max	...	8
Nickel and alloys									
Alloy 825	N08825	...	Metal (pickling); field or pilot plant test; strong aeration; slight to moderate agitation. Hydrogen chloride fumes from tank containing approx. 19% hydrochloric acid	...	71-82 (160-180)	41 d	0.10 (5.9)	Severe pitting	89
Nickel 201	N02201	...	Dry	...	538 (1000)	20 h	0.925 (37)	...	44
Nickel 201	N02201	...	Wet, moisture content about 0.25%	...	538 (1000)	4 h	3 (120)	...	44
Nickel 201	N02201	...	Wet, moisture content about 0.25%	...	538 (1000)	8 h	1.75 (70)	...	44
Nickel 201	N02201	...	Wet, moisture content about 0.25%	...	538 (1000)	20 h	0.7 (28)	...	44
Refractory metals and alloys									
Titanium	...	...	Gas. Air mixture	...	25-100 (77-212)	...	Resistant	...	90
Stainless steels									
301	S30100	...	Gas	...	20 (68)	...	Good	Pitting	253
301	S30100	...	Gas	...	50 (122)	...	Good	Pitting	253
301	S30100	...	Gas	...	100 (212)	...	Questionable	Pitting	253
301	S30100	...	Gas	...	400 (752)	...	Poor	Pitting	253
302	S30200	...	Gas	...	20 (68)	...	Good	Pitting	253
302	S30200	...	Gas	...	50 (122)	...	Good	Pitting	253
302	S30200	...	Gas	...	100 (212)	...	Questionable	Pitting	253
302	S30200	...	Gas	...	400 (752)	...	Poor	Pitting	253
303	S30300	...	Gas	...	20 (68)	...	Questionable	Pitting	253
303	S30300	...	Gas	...	20 (68)	...	Good	Pitting	253
303	S30300	...	Gas	...	50 (122)	...	Questionable	Pitting	253
303	S30300	...	Gas	...	50 (122)	...	Good	Pitting	253
303	S30300	...	Gas	...	100 (212)	...	Poor	Pitting	253
303	S30300	...	Gas	...	100 (212)	...	Questionable	Pitting	253
303	S30300	...	Gas	...	400 (752)	...	Poor	Pitting	253
303	S30300	...	Gas	...	400 (752)	...	Poor	Pitting	253
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Hydrogen chloride, dry, plus 2% acetic acid, 3% acetyl chloride	95	11 (52)	14 d	4.9 (196)	...	89
304	S30400	...	Gas	...	20 (68)	...	Good	Pitting	253
304	S30400	...	Gas	...	50 (122)	...	Good	Pitting	253
304	S30400	...	Gas	...	100 (212)	...	Questionable	Pitting	253
304	S30400	...	Gas	...	400 (752)	...	Poor	Pitting	253
304	S30400	...	Metal (pickling); field or pilot plant test; strong aeration; slight to moderate agitation. Hydrogen chloride fumes from tank containing approx. 19% hydrochloric acid	...	70-82 (160-180)	41 d	0.22 (8.6)	Severe pitting	89
304	S30400	...	Research lab test; rapid agitation. Hydrogen chloride, dry	...	204 (400)	...	0.13 (5) max	...	89
304	S30400	...	Textile processing; field or pilot plant test; slight to moderate aeration; no agitation. Hydrogen chloride made by volatilizing 31.5% hydrochloric acid solution (shaft leading to wool-rag carbonizer)	...	104 (220)	37 d	0.16 (6.5)	Slight pitting. Crevice attack	89
304L	S30403	...	Atomic energy; field or pilot plant test. Hydrogen chloride, dry	...	499 (930)	21 d	0.28 (11)	...	89
304L	S30403	...	Gas	...	20 (68)	...	Good	Pitting	253

(Continued)

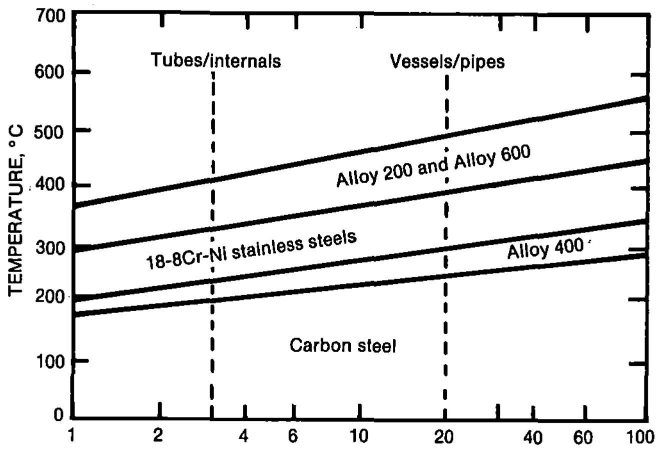
Corrosion Behavior of Various Metals and Alloys in Hydrogen Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	Gas	...	50 (122)	...	Good	Pitting	253
304L	S30403	...	Gas	...	100 (212)	...	Questionable	Pitting	253
304L	S30403	...	Gas	...	400 (752)	...	Poor	Pitting	253
304LN	S30453	...	Gas	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	Gas	...	50 (122)	...	Good	Pitting	253
304LN	S30453	...	Gas	...	100 (212)	...	Questionable	Pitting	253
304LN	S30453	...	Gas	...	400 (752)	...	Poor	Pitting	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Hydrogen chloride, dry, plus 2% acetic acid, 3% acetyl chloride	95	11 (52)	14 d	3.5 (139)	...	89
316	S31600	...	Gas	...	20 (68)	...	Good	Pitting	253
316	S31600	...	Gas	...	50 (122)	...	Good	Pitting	253
316	S31600	...	Gas	...	100 (212)	...	Good	Pitting	253
316	S31600	...	Gas	...	400 (752)	...	Poor	Pitting	253
316	S31600	...	Metal (pickling); field or pilot plant test; strong aeration; slight to moderate agitation. Hydrogen chloride fumes from tank containing approx. 19% hydrochloric acid	...	71-82 (160-180)	41 d	0.18 (7.1)	Severe pitting	89
316	S31600	...	Petroleum processing; field or pilot plant test. Hydrogen chloride, dry, pressure	...	82 (180)	234 d	0.19 (7.5)	...	89
316	S31600	...	Research lab test; rapid agitation. Hydrogen chloride, dry	...	204 (400)	...	0.13 (5) max	...	89
316	S31600	...	Textile processing; field or pilot plant test; slight to moderate aeration; no agitation. Hydrogen chloride made by volatilizing 31.5% hydrochloric acid solution (shaft leading to wool-rag carbonizer)	...	104 (220)	37 d	0.09 (3.6)	Slight pitting. Crevice attack	89
316F	S31620	...	Gas	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	Gas	...	50 (122)	...	Good	Pitting	253
316F	S31620	...	Gas	...	100 (212)	...	Questionable	Pitting	253
316F	S31620	...	Gas	...	400 (752)	...	Poor	Pitting	253
316L	S31603	...	Gas	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	Gas	...	50 (122)	...	Good	Pitting	253
316L	S31603	...	Gas	...	100 (212)	...	Good	Pitting	253
316L	S31603	...	Gas	...	400 (752)	...	Poor	Pitting	253
316LN	S31653	...	Gas	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	Gas	...	50 (122)	...	Good	Pitting	253
316LN	S31653	...	Gas	...	100 (212)	...	Good	Pitting	253
316LN	S31653	...	Gas	...	400 (752)	...	Poor	Pitting	253
316Ti	S31635	...	Gas	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	Gas	...	50 (122)	...	Good	Pitting	253
316Ti	S31635	...	Gas	...	100 (212)	...	Good	Pitting	253
316Ti	S31635	...	Gas	...	400 (752)	...	Poor	Pitting	253
317L	S31703	...	Gas	...	20 (68)	...	Good	Pitting	253
317L	S31703	...	Gas	...	50 (122)	...	Good	Pitting	253
317L	S31703	...	Gas	...	100 (212)	...	Good	Pitting	253
317L	S31703	...	Gas	...	400 (752)	...	Poor	Pitting	253
317LN	S31725	...	Gas	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	Gas	...	50 (122)	...	Good	Pitting	253
317LN	S31725	...	Gas	...	100 (212)	...	Good	Pitting	253
317LN	S31725	...	Gas	...	400 (752)	...	Poor	Pitting	253
321	S32100	...	Gas	...	20 (68)	...	Good	Pitting	253
321	S32100	...	Gas	...	50 (122)	...	Good	Pitting	253

(Continued)

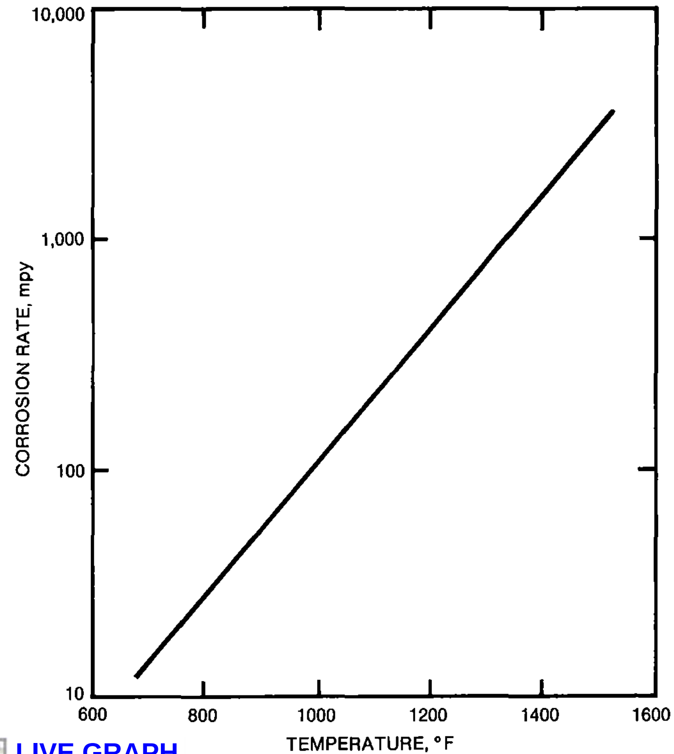
Corrosion Behavior of Various Metals and Alloys in Hydrogen Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	Gas	...	100 (212)	...	Questionable	Pitting	253
321	S32100	...	Gas	...	400 (752)	...	Poor	Pitting	253
329	S32900	...	Gas	...	20 (68)	...	Good	Pitting	253
329	S32900	...	Gas	...	50 (122)	...	Good	Pitting	253
329	S32900	...	Gas	...	100 (212)	...	Good	Pitting	253
329	S32900	...	Gas	...	400 (752)	...	Poor	Pitting	253
347	S34700	...	Gas	...	20 (68)	...	Good	Pitting	253
347	S34700	...	Gas	...	50 (122)	...	Good	Pitting	253
347	S34700	...	Gas	...	100 (212)	...	Questionable	Pitting	253
347	S34700	...	Gas	...	400 (752)	...	Poor	Pitting	253
403	S40300	...	Gas	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	Gas	...	50 (122)	...	Poor	Pitting	253
403	S40300	...	Gas	...	100 (212)	...	Poor	Pitting	253
403	S40300	...	Gas	...	400 (752)	...	Poor	Pitting	253
405	S40500	...	Gas	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	Gas	...	50 (122)	...	Poor	Pitting	253
405	S40500	...	Gas	...	100 (212)	...	Poor	Pitting	253
405	S40500	...	Gas	...	400 (752)	...	Poor	Pitting	253
409	S40900	...	Gas	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	Gas	...	50 (122)	...	Poor	Pitting	253
409	S40900	...	Gas	...	100 (212)	...	Poor	Pitting	253
409	S40900	...	Gas	...	400 (752)	...	Poor	Pitting	253
410	S41000	...	Gas	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	Gas	...	50 (122)	...	Poor	Pitting	253
410	S41000	...	Gas	...	100 (212)	...	Poor	Pitting	253
410	S41000	...	Gas	...	400 (752)	...	Poor	Pitting	253
416	S41600	...	Gas	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	Gas	...	50 (122)	...	Poor	Pitting	253
416	S41600	...	Gas	...	100 (212)	...	Poor	Pitting	253
416	S41600	...	Gas	...	400 (752)	...	Poor	Pitting	253
420	S42000	...	Gas	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	Gas	...	50 (122)	...	Poor	Pitting	253
420	S42000	...	Gas	...	100 (212)	...	Poor	Pitting	253
420	S42000	...	Gas	...	400 (752)	...	Poor	Pitting	253
430	S43000	...	Gas	...	20 (68)	...	Questionable	Pitting	253
430	S43000	...	Gas	...	50 (122)	...	Questionable	Pitting	253
430	S43000	...	Gas	...	100 (212)	...	Poor	Pitting	253
430	S43000	...	Gas	...	400 (752)	...	Poor	Pitting	253
434	S43400	...	Gas	...	50 (122)	...	Good	Pitting	253
434	S43400	...	Gas	...	100 (212)	...	Questionable	Pitting	253
434	S43400	...	Gas	...	400 (752)	...	Poor	Pitting	253
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Hydrogen chloride, dry, plus 2% acetic acid, 3% acetyl chloride	95	11 (52)	14 d	1.1 (42)	...	89
Carpenter 20	...	...	Metal (pickling); field or pilot plant test; strong aeration; slight to moderate agitation. Hydrogen chloride fumes from tank containing approx. 19% hydrochloric acid	...	71-82 (160-180)	41 d	0.22 (8.6)	Slight pitting	89
F51	S31803	...	Gas	...	20 (68)	...	Good	Pitting	253
F51	S31803	...	Gas	...	50 (122)	...	Good	Pitting	253
F51	S31803	...	Gas	...	100 (212)	...	Good	Pitting	253
F51	S31803	...	Gas	...	400 (752)	...	Poor	Pitting	253



LIVE GRAPH
Click here to view

Various alloys. Upper temperature design limits for various alloys in hydrogen chloride. Source: T.F. Degnan, "Materials of Construction for Hydrochloric Acid and Hydrogen Chloride," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986, 267.



LIVE GRAPH
Click here to view

Inconel 600. Corrosion rates in dry hydrogen gas. Source: Inco Alloys International, 1962.

Hydrogen Cyanide

Hydrogen cyanide, HCN, also known as hydrocyanic acid, prussic acid, and formonitrile, is a very poisonous colorless gas with a characteristic fragrance of bitter almonds. Small amounts of hydrogen cyanide derivatives in combination with glucose and benzaldehyde are found in nature in apricot, peach, cherry, and plum pits. It liquifies at 26 °C (79 °F) and is soluble in water, alcohol, and ether. Hydrogen cyanide is usually sold commercially as an aqueous solution containing 2 to 10% hydrogen cyanide. The aqueous solutions of hydrogen cyanide decompose slowly to form ammonium formate. In some uses, it is preferable to generate hydrogen cyanide as needed, thus eliminating handling and storage problems. Hydrogen cyanide is used in manufacturing cyanide salts, acrylonitrile, and dyes. It is also used as a horticultural fumigant.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Hydrogen cyanide has been manufactured in aluminum alloy reactor towers, heat exchangers, tanks, and piping. Aluminum alloy 3003 resisted hydrogen cyanide at ambient temperature in laboratory tests.

Copper. Copper and copper alloys can be used to handle hydrogen cyanide.

Gold. Gold is rapidly attacked by hydrogen cyanide in the presence of oxygen.

Titanium. Titanium alloys have a protective oxide film that resists attack by hydrogen cyanide at temperatures above 150 °C (300 °F).

Corrosion Behavior of Various Metals and Alloys in Hydrogen Cyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Electrolytic Copper	C11000	...	At base of partial condenser	...	...	573 h	14.2 (560) max	...	138
Electrolytic Copper	C11000	...	At base of partial condenser	...	...	671 h	0.48 (19)	...	138
Electrolytic Copper	C11000	...	At base of stripping still	...	...	573 h	1.2 (47) max	...	138
Electrolytic Copper	C11000	...	At base of stripping still	...	...	671 h	Resistant	...	138
Electrolytic Copper	C11000	...	At top of HCN refining still	...	...	573 h	0.06 (2.4) max	...	138
Electrolytic Copper	C11000	...	At top of HCN refining still	...	...	671 h	0.03 (1.0) max	...	138
Electrolytic Copper	C11000	...	Cyanohydrin stripping still products (kettle)	...	...	1621 h	0.68 (27)	...	138
Electrolytic Copper	C11000	...	Ethylene cyanohydrin residues	...	70 (158)	3144 h	0.04 (1.4) max	...	138
Electrolytic Copper	C11000	...	Ethylene cyanohydrin residues	...	30-90 (86-194)	2232 h	0.01 (0.5)	...	138
Electrolytic Copper	C11000	...	Stripping still	...	...	573 h	0.22 (8.6) max	...	138
Electrolytic Copper	C11000	...	Stripping still	...	...	671 h	0.61 (24) max	...	138
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	At base of partial condenser	...	...	573 h	5.4 (210) max	...	138
Silicon bronze, high	C65500	...	At base of partial condenser	...	...	671 h	0.34 (14)	...	138
Silicon bronze, high	C65500	...	At base of stripping still	...	...	573 h	1.1 (45) max	...	138
Silicon bronze, high	C65500	...	At base of stripping still	...	...	671 h	0.28 (11)	...	138
Silicon bronze, high	C65500	...	At top of HCN refining still	...	...	573 h	0.25 (1.0) max	...	138
Silicon bronze, high	C65500	...	Cyanohydrin stripping still products (kettle)	...	...	1621 h	0.035 (1.4)	...	138
Silicon bronze, high	C65500	...	Ethylene cyanohydrin residues	...	30-90 (86-194)	2232 h	0.04 (1.6)	...	138
Silicon bronze, high	C65500	...	Stripping still	...	...	573 h	0.24 (10) max	...	138
Silicon bronze, high	C65500	...	Stripping still	...	...	671 h	0.50 (20) max	...	138
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Liquid hydrocyanic acid	...	7 (45)	169 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Liquid hydrocyanic acid	...	7 (45)	169 d	0.003 (0.1) max	...	89
410	S41000	...	...	...	Room	...	Poor	...	121

Hydrogen Peroxide

Hydrogen peroxide, H_2O_2, is a colorless, viscous, unstable liquid that has a boiling point of 158 °C (316 °F). It is soluble in water and in alcohol. The highly reactive hydrogen peroxide molecule is often used as an intermediate in chemical synthesis involving oxidation, epoxidation, and hydroxylation. Hydrogen peroxide has been used as an oxidizer in various fuel mixtures for rockets and torpedoes. Hydrogen peroxide at low concentrations (around 3%) is used as an antiseptic in medicine and at higher concentrations as an antimicrobial agent to sterilize processing equipment and packaging materials for aseptic packaging. It is widely used as a bleaching agent for wool, cotton, groundwood pulp, and cosmetically in formulations for bleaching hair.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy equipment has been used in distilling, shipping, and storing hydrogen peroxide. Aluminum alloy 1060 has been the choice for long-term storage, whereas the 5XXX series alloys have been selected for short-term storage. Piping of aluminum alloy 6063 has been used in the service of hydrogen peroxide. In laboratory conditions of ambient temperature and chloride-free hydrogen peroxide, aluminum alloys 1060, 5052, and 6063 were resistant to attack.

Nickel. Nickel alloy 600 resists alkaline solutions containing hydrogen peroxide.

Tantalum. Tantalum is not attacked by hydrogen peroxide at ordinary temperatures.

Titanium. The corrosion rate of titanium alloys depends on the concentration, temperature, and pH of the hydrogen peroxide solutions. Corrosion rates are low in dilute neutral solutions, but increase rapidly in alkaline solutions due to the formation of soluble titanium-peroxyl compounds. In concentrated (90%) hydrogen peroxide solutions, the corrosion rate is rapid.

Corrosion Behavior of Various Metals and Alloys in Hydrogen Peroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	All	Room	...	Poor	...	119
Refractory metals and alloys									
Niobium	R04210	...	...	30	Room	...	0.025 (1.0)	...	2
Niobium	R04210	...	...	30	Boiling	...	0.5 (20)	...	2
Titanium	...	...	...	3	Room	...	0.127 (5.08) max	...	90
Titanium	...	...	...	6	Room	...	0.127 (5.08) max	...	90
Titanium	...	...	...	30	Room	...	0.305 (12.2) max	...	90
Titanium	...	...	pH 1	5	66 (151)	...	0.152 (6.08)	...	90
Titanium	...	...	pH 1	20	66 (151)	...	0.69 (27.6)	...	90
Titanium	...	...	pH 11	0.08	70 (158)	...	0.42 (16.8)	...	90
Titanium	...	...	pH 4	5	66 (151)	...	0.061 (2.44)	...	90
Titanium	...	...	Plus 2% NaOH	1	60 (140)	...	55.9 (2236)	...	90
Titanium, grade 2	R50400	...	pH 1. Acid solutions were prepared with HCl additions	5	23 (73)	...	0.064 (2.5)	...	27
Titanium, grade 2	R50400	...	pH 1. Acid solutions were prepared with HCl additions	5	66 (150)	...	0.152 (6.0)	...	27
Titanium, grade 2	R50400	...	pH 1. Acid solutions were prepared with HCl additions	20	66 (150)	...	0.686 (27.0)	...	27
Titanium, grade 2	R50400	...	pH 1. Plus 500 ppm Ca^{2+}. Acid solutions were prepared with HCl additions	5	66 (150)	...	Resistant	...	27
Titanium, grade 2	R50400	...	pH 1. Plus 500 ppm Ca^{2+}. Acid solutions were prepared with HCl additions	20	66 (150)	...	Resistant	...	27
Titanium, grade 2	R50400	...	pH 11. Acid solutions were prepared with HCl additions.	0.75 g/L	70 (160)	...	0.42 (16.5)	...	27
Titanium, grade 2	R50400	...	pH 4.3. Acid solutions were prepared with HCl additions	5	23 (73)	...	0.013 (0.5)	...	27

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Peroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium, grade 2	R50400	...	pH 4.3. Acid solutions were prepared with HCl additions	5	66 (150)	...	0.061 (2.4)	...	27
Titanium, grade 2	R50400	...	Plus 10 g/L NaOH plus 10 g/L Na_2SiO_3 plus 0.5 g/L Na_3PO_4	3.5 g/L	60 (140)	...	Resistant	...	27
Titanium, grade 2	R50400	...	Plus 20 g/L NaOH	10 g/L	60 (140)	...	55.9 (2200.0)	...	27
Titanium, grade 7	R52400	...	pH 1	5	23 (72)	...	0.062 (2.44)	...	33
Titanium, grade 7	R52400	...	pH 1	5	66 (150)	...	0.127 (5.0)	...	33
Titanium, grade 7	R52400	...	pH 4	5	23 (72)	...	0.010 (0.39)	...	33
Titanium, grade 7	R52400	...	pH 4	5	66 (150)	...	0.046 (1.81)	...	33
Titanium, grade 7	R52400	...	Plus 5% NaCl, pH 1	20	66 (150)	...	0.008 (0.315)	...	33
Titanium, grade 7	R52400	...	Plus 500 ppm Ca^{2+}, pH 1	5	66 (150)	...	Resistant	...	33
Titanium, grade 7	R52400	...	Plus 500 ppm Ca^{2+}, pH 1	20	66 (150)	...	0.76 (29.9)	...	33
Zr702	R60702	...	...	50	100 (212)	...	0.05 (2) max	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus acetic acid, cationic resin, acetylated castor oil during 8 h; and alkaline wash, water wash, sodium sulfate during 6 h (epoxydation reactor)	50	100 (212)	1 d	0.7 (27)	Crevice attack	89
304	S30400	...	Chemical processing; lab test; no aeration; rapid agitation. Stabilized with sulfuric acid	30	29 (85)	6 d	0.003 (0.1) max	...	89
304	S30400	...	Cosmetic processing; lab test; no aeration; no agitation. Stabilized with acetanilide and phosphoric acid	6.1	Room	30 d	0.003 (0.1) max	...	89
304	S30400	...	Cosmetic processing; lab test; no aeration; rapid agitation. Stabilized with acetanilide	3	Room	30 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus acetic acid, cationic resin, acetylated castor oil during 8 h; and alkaline wash, water wash, sodium sulfate during 6 h (epoxydation reactor)	50	100 (212)	1 d	0.2 (8)	Crevice attack	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation; sensitized specimens. Plus acetic acid, cationic resin, acetylated castor oil during 8 h; and alkaline wash, water wash, sodium sulfate during 6 h (epoxydation reactor)	50	100 (212)	1 d	1.5 (59)	Crevice attack	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Peroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Hydrogen Sulfide

Hydrogen sulfide, H_2S, is a flammable, toxic, colorless, malodorous gas that is soluble in water and in alcohol. It boils at –60 °C (–76 °F). This gas requires careful handling because of its toxicity and explosiveness. It is especially dangerous from the standpoint of toxicity, because it can paralyze the olfactory nerves. Its explosiveness stems from a low ignition temperature (260 °C, or 500 °F) and a wide flammability range (from 4.3 to 44 vol% in air). Upon burning, hydrogen sulfide liberates a considerable amount of heat. It is produced by water hydrolysis of elements higher in the hydrogen scale and by acid hydrolysis of sulfides.

Hydrogen sulfide reacts with the elements of fluorine, chlorine, bromine, and iodine to form the corresponding halogen acids. When hydrogen sulfide is introduced into solutions of heavy metals such as silver, lead, copper, and manganese, metal sulfides are formed. Such reactions form the basis for separation of these heavy metals in classical wet qualitative analytical methods and for tarnishing of silver. Hydrogen sulfide also reacts with a large number of organic compounds.

When dissolved in water, hydrogen sulfide is a weak acid and is therefore corrosive because it is a source of hydrogen ions. In the absence of buffering ions, water equilibrated with 1 atm of hydrogen sulfide has a pH of about 4. However, under high-pressure formation conditions, pH values as low as 3 have been calculated.

Hydrogen sulfide is used as an analytical reagent, as a source of sulfur, in the preparation of sulfides (sodium sulfide and sodium hydrosulfide) and sulfur-bearing organic compounds (mercaptans, thiophenes, and organic sulfides), for purification of hydrochloric and sulfuric acids, in the production of extreme pressure lubricants, in the formulation of rare-earth phosphors for use in color television tubes, and in removal of copper, cadmium, and titanium from spent catalysts.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Alloy Steels. Alloy steels used in oil and natural gas wells and pipelines are often subject to corrosion by hydrogen sulfide. For the casing of deep wells, high-strength alloy steels are usually required. Furthermore, very hostile environments are often encountered—in particular, high hydrogen sulfide levels. In deep gas wells, for example, formations have been encountered with hydrogen sulfide concentrations ranging from less than 1% to greater than 50%. In addition, temperatures up to 200 °C (390 °F) can be found, along with pressures to 140 MPa (20 ksi). Also, hydrogen sulfide is often found in combination with chloride-containing brines and carbon dioxide, which add to the harshness of the environment.

Chemical inhibition is frequently used in deep wells to control weight loss corrosion from hydrogen sulfide. However, hydrogen sulfide can also produce embrittlement of high-strength steels. This phenomena, known as sulfide stress cracking, depends on hydrogen sulfide concentration and temperature among other factors.

Linepipe steels can be susceptible to a specialized form of hydrogen damage when hydrogen sulfide is present in oil and gas. This type of embrittlement, known as hydrogen-induced cracking or stepwise cracking, results from the accumulation of hydrogen at internal surfaces within the steel such as interfaces at nonmetallic inclusions. Microcracks that form at these interfaces grow in a stepwise fashion toward the surface of

the pipe, resulting in failure. Several failures due to hydrogen-induced cracking have been reported, and when they occur, they can be catastrophic.

Aluminum. In laboratory tests, aluminum alloys 1100 and 3003 have suffered mild attack (corrosion rates of about 0.05 mm/yr, or 2 mils/yr) by aqueous solutions of hydrogen sulfide and by hydrogen sulfide gas. Aluminum alloys have been used in refineries for handling hydrocarbon liquids and vapors containing hydrogen sulfide. These applications have included bubble caps, heat exchangers, and roofs on storage tanks for sour crude oils.

Copper. Moist hydrogen sulfide gas, as well as other sulfur compounds such as sodium sulfide and potassium sulfide, react with copper and copper-zinc alloys to form CuS. Reaction rates depend on alloy composition: alloys containing more than 20% Zn have considerably better resistance than lower zinc alloys or copper. Hot, wet hydrogen sulfide vapors corrode C26000, C28000, and C44300 at rates of only 50 to 75 μm/yr (2 to 3 mils/yr), but the rates for C11000 and C23000 under the same conditions are 1250 to 1625 μm/yr (50 to 65 mils/yr).

Nickel. Nickel alloy B-2 is susceptible to hydrogen embrittlement in hydrogen sulfide-containing environments even in the annealed condition.

Incoloy alloy 825 is used to resist the corrosive conditions in sour gas and oil wells. The environments include hydrogen sulfide and carbon dioxide in sour crude and gas at high temperatures and pressures. The NACE test was used to evaluate alloys for such service. The test consists of exposure of stressed, steel-coupled C-rings to a room-temperature solution of 5% sodium chloride with 0.5% acetic acid and saturated with hydrogen sulfide. The specimens of Incoloy alloy 825 were stressed at 100% of yield strength (0.2% offset). No failure occurred in the test period of 48 or 50 days.

Monel alloy K-500 has been found to be resistant to a sour gas environment. After 6 days of continuous immersion in saturated (3500 ppm) hydrogen sulfide solutions at acidic and basic pH (ranging from 1.0 to 11.0), U-bend specimens of age-hardened sheet showed no cracking. There was some tightly adherent black scale. Hardness of the specimens ranged from 28 to 40 HRC.

Alloy 800 has good resistance to hydrogen sulfide, a substance often encountered in petrochemical processing. Specimens of alloy 800 exposed to process gases containing hydrogen sulfide in various areas of a catalytic reformer exhibited corrosion rates of less than 0.03 mm/yr (1 mil/yr).

Palladium. Hydrogen sulfide at temperatures above 600 °C (1110 °F) attacks palladium and produces a low-melting phase. The standard electrode potential is approximately +0.83 V at 25 °C (75 °F).

Tantalum. Over the temperature range commonly used in solution processes, tantalum is inert to hydrogen sulfide.

Tin. From 25 to 100 °C (75 to 212 °F), hydrogen sulfide has little apparent effect on tin, but above 100 °C (212 °F), stannous sulfide (SnS) forms.

Titanium. The oxide film on titanium alloys provides an effective barrier to attack by hydrogen sulfide (as well as by most other gases). Corrosion rates are near zero over the full concentration range to temperatures well beyond boiling.

Tests in acidic NaCl brine environments containing hydrogen sulfide indicate that titanium alloys are immune to stress-corrosion cracking at stress levels up to their yield strengths. Elevated temperature tests in hydrogen sulfide brines indicate that Ti-3Al-8V-6Cr-4Mo-4Zr is susceptible to stress-corrosion cracking.

Zinc. Hydrogen sulfide is harmless to zinc because insoluble zinc sulfide (ZnS) is formed.

Zirconium. Zirconium is resistant to stress-corrosion cracking in hydrogen sulfide.

Corrosion Behavior of Various Metals and Alloys in Hydrogen Sulfide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Poor	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Questionable	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Poor	...	93
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Questionable	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Poor	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Sulfide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Questionable	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Questionable	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Questionable	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Poor	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Poor	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Poor	...	93
Miscellaneous									
Gold	P00016	...	Moist	...	Room	...	0.05 (2) max	...	8
Iridium	...	...	Moist	...	Room	...	Resistant	...	18
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Osmium	...	...	Moist	...	Room	...	0.25 (10) max	...	26
Palladium	P03980	...	Moist	...	Room	...	Resistant	...	17
Platinum	P04995	...	Moist	...	Room	...	Resistant	...	6
Rhodium	P05990	...	Moist	...	Room	...	Resistant	...	29
Rhodium	P05990	...	Moist	...	Room	...	Resistant	...	18
Rhodium	P05990	...	Moist at room temperature	...	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	All	Room	...	Resistant	...	9
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Hydrogen sulfide, water (extraction unit)	...	80-150 (176-302)	160 d	0.005 (0.2)	Slight pitting; crevice attack	89
Refractory metals and alloys									
Titanium	...	...	Steam and 0.077% mercaptans	7.65	93-110 (200-230)	...	Resistant	...	90
Titanium	...	...	Water saturated	...	21 (70)	...	0.003 (0.12) max	...	90
Stainless steels									
301	S30100	...	Dry	4 max	20 (68)	...	Resistant	...	253
301	S30100	...	Dry	4 max	100 (212)	...	Resistant	...	253
301	S30100	...	Dry	4 max	400 max	...	Resistant	...	253
301	S30100	...	Moist	4 max	400 max	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Sulfide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	Dry	4 max	20 (68)	...	Resistant	...	253
302	S30200	...	Dry	4 max	100 (212)	...	Resistant	...	253
302	S30200	...	Dry	4 max	400 max	...	Resistant	...	253
302	S30200	...	Moist	4 max	400 max	...	Resistant	...	253
303	S30300	...	Dry	4 max	20 (68)	...	Resistant	...	253
303	S30300	...	Dry	4 max	20 (68)	...	Resistant	...	253
303	S30300	...	Dry	4 max	100 (212)	...	Resistant	...	253
303	S30300	...	Dry	4 max	100 (212)	...	Resistant	...	253
303	S30300	...	Dry	4 max	400 max	...	Questionable	...	253
303	S30300	...	Dry	4 max	400 max	...	Resistant	...	253
303	S30300	...	Moist	4 max	400 max	...	Poor	...	253
303	S30300	...	Moist	4 max	400 max	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test. Hydrogen sulfide (generator, vapors)	...	...	56 d	0.003 (0.1) max	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Hydrogen sulfide, water (extraction unit)	...	80-150 (176-302)	160 d	0.003 (0.1) max	Slight pitting; crevice attack	89
304	S30400	...	Dry	4 max	20 (68)	...	Resistant	...	253
304	S30400	...	Dry	4 max	100 (212)	...	Resistant	...	253
304	S30400	...	Dry	4 max	400 max	...	Resistant	...	253
304	S30400	...	Moist	4 max	400 max	...	Resistant	...	253
304	S30400	...	Petroleum processing; field or pilot plant test; no aeration; rapid agitation. Plus 3-17 mol% ammonia, 7-12% carbon dioxide, small amounts of chlorides, cyanides and hydrocarbons (vapors)	85-65 mol%	127 (260)	288 d	0.003 (0.1) max	...	89
304	S30400	...	Petroleum processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus air and nitrogen	98	32 (90)	188 d	0.003 (0.1) max	Crevice attack	89
304L	S30403	...	Dry	4 max	20 (68)	...	Resistant	...	253
304L	S30403	...	Dry	4 max	100 (212)	...	Resistant	...	253
304L	S30403	...	Dry	4 max	400 max	...	Resistant	...	253
304L	S30403	...	Moist	4 max	400 max	...	Resistant	...	253
304LN	S30453	...	Dry	4 max	20 (68)	...	Resistant	...	253
304LN	S30453	...	Dry	4 max	100 (212)	...	Resistant	...	253
304LN	S30453	...	Dry	4 max	400 max	...	Resistant	...	253
304LN	S30453	...	Moist	4 max	400 max	...	Resistant	...	253
316	S31600	...	Chemical processing; field or pilot plant test. Hydrogen sulfide (generator, vapors)	...	...	56 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration. Hydrogen-sulfide gas saturated with water vapor.	...	38-77 (100-170)	60 d	0.003 (0.1)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Hydrogen sulfide, water (extraction unit)	...	80-150 (176-302)	160 d	0.003 (0.1) max	Slight pitting; crevice attack	89

(Continued)

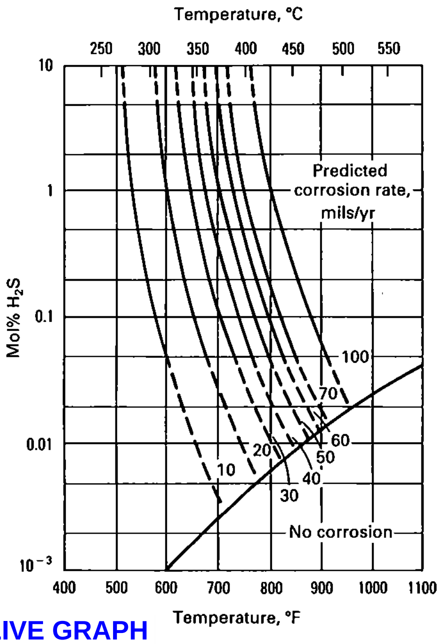
Corrosion Behavior of Various Metals and Alloys in Hydrogen Sulfide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Dry	4 max	20 (68)	...	Resistant	...	253
316	S31600	...	Dry	4 max	100 (212)	...	Resistant	...	253
316	S31600	...	Dry	4 max	400 max	...	Resistant	...	253
316	S31600	...	Moist	4 max	400 max	...	Resistant	...	253
316	S31600	...	Petroleum processing; field or pilot plant test; no aeration; rapid agitation. Plus 3-17 mol% ammonia, 7-12% carbon dioxide, small amounts of chlorides, cyanides and hydrocarbons (vapors)	85-65 mol%	127 (260)	288 d	0.003 (0.1) max	...	89
316	S31600	...	Petroleum processing; field or pilot plant test; strong aeration; slight to moderate agitation. Plus air and nitrogen	98	32 (90)	188 d	0.003 (0.1) max	Slight pitting	89
316F	S31620	...	Dry	4 max	20 (68)	...	Resistant	...	253
316F	S31620	...	Dry	4 max	100 (212)	...	Resistant	...	253
316F	S31620	...	Dry	4 max	400 max	...	Resistant	...	253
316F	S31620	...	Moist	4 max	400 max	...	Resistant	...	253
316L	S31603	...	Dry	4 max	20 (68)	...	Resistant	...	253
316L	S31603	...	Dry	4 max	100 (212)	...	Resistant	...	253
316L	S31603	...	Dry	4 max	400 max	...	Resistant	...	253
316L	S31603	...	Moist	4 max	400 max	...	Resistant	...	253
316LN	S31653	...	Dry	4 max	20 (68)	...	Resistant	...	253
316LN	S31653	...	Dry	4 max	100 (212)	...	Resistant	...	253
316LN	S31653	...	Dry	4 max	400 max	...	Resistant	...	253
316LN	S31653	...	Moist	4 max	400 max	...	Resistant	...	253
316Ti	S31635	...	Dry	4 max	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Dry	4 max	100 (212)	...	Resistant	...	253
316Ti	S31635	...	Dry	4 max	400 max	...	Resistant	...	253
316Ti	S31635	...	Moist	4 max	400 max	...	Resistant	...	253
317L	S31703	...	Dry	4 max	20 (68)	...	Resistant	...	253
317L	S31703	...	Dry	4 max	100 (212)	...	Resistant	...	253
317L	S31703	...	Dry	4 max	400 max	...	Resistant	...	253
317L	S31703	...	Moist	4 max	400 max	...	Resistant	...	253
317LN	S31725	...	Dry	4 max	20 (68)	...	Resistant	...	253
317LN	S31725	...	Dry	4 max	100 (212)	...	Resistant	...	253
317LN	S31725	...	Dry	4 max	400 max	...	Resistant	...	253
317LN	S31725	...	Moist	4 max	400 max	...	Resistant	...	253
321	S32100	...	Dry	4 max	20 (68)	...	Resistant	...	253
321	S32100	...	Dry	4 max	100 (212)	...	Resistant	...	253
321	S32100	...	Dry	4 max	400 max	...	Resistant	...	253
321	S32100	...	Moist	4 max	400 max	...	Resistant	...	253
329	S32900	...	Dry	4 max	20 (68)	...	Resistant	...	253
329	S32900	...	Dry	4 max	100 (212)	...	Resistant	...	253
329	S32900	...	Dry	4 max	400 max	...	Resistant	...	253
329	S32900	...	Moist	4 max	400 max	...	Resistant	...	253
347	S34700	...	Dry	4 max	20 (68)	...	Resistant	...	253
347	S34700	...	Dry	4 max	100 (212)	...	Resistant	...	253
347	S34700	...	Dry	4 max	400 max	...	Resistant	...	253
347	S34700	...	Moist	4 max	400 max	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydrogen Sulfide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	Dry	4 max	20 (68)	...	Resistant	...	253
403	S40300	...	Dry	4 max	100 (212)	...	Resistant	...	253
403	S40300	...	Dry	4 max	400 max	...	Questionable	...	253
403	S40300	...	Moist	4 max	400 max	...	Poor	...	253
405	S40500	...	Dry	4 max	20 (68)	...	Resistant	...	253
405	S40500	...	Dry	4 max	100 (212)	...	Resistant	...	253
405	S40500	...	Dry	4 max	400 max	...	Questionable	...	253
405	S40500	...	Moist	4 max	400 max	...	Poor	...	253
409	S40900	...	Dry	4 max	20 (68)	...	Resistant	...	253
409	S40900	...	Dry	4 max	100 (212)	...	Resistant	...	253
409	S40900	...	Dry	4 max	400 max	...	Questionable	...	253
409	S40900	...	Moist	4 max	400 max	...	Poor	...	253
410	S41000	...	Dry	4 max	20 (68)	...	Resistant	...	253
410	S41000	...	Dry	4 max	100 (212)	...	Resistant	...	253
410	S41000	...	Dry	4 max	400 max	...	Questionable	...	253
410	S41000	...	Moist	4 max	400 max	...	Poor	...	253
416	S41600	...	Dry	4 max	20 (68)	...	Resistant	...	253
416	S41600	...	Dry	4 max	100 (212)	...	Resistant	...	253
416	S41600	...	Dry	4 max	400 max	...	Questionable	...	253
416	S41600	...	Moist	4 max	400 max	...	Poor	...	253
420	S42000	...	Dry	4 max	20 (68)	...	Resistant	...	253
420	S42000	...	Dry	4 max	100 (212)	...	Resistant	...	253
420	S42000	...	Dry	4 max	400 max	...	Questionable	...	253
420	S42000	...	Moist	4 max	400 max	...	Poor	...	253
430	S43000	...	Dry	4 max	20 (68)	...	Resistant	...	253
430	S43000	...	Dry	4 max	100 (212)	...	Resistant	...	253
430	S43000	...	Dry	4 max	400 max	...	Questionable	...	253
430	S43000	...	Moist	4 max	400 max	...	Poor	...	253
434	S43400	...	Dry	4 max	20 (68)	...	Resistant	...	253
434	S43400	...	Dry	4 max	100 (212)	...	Resistant	...	253
434	S43400	...	Dry	4 max	400 max	...	Good	...	253
434	S43400	...	Moist	4 max	400 max	...	Good	...	253
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no aeration. Hydrogen-sulfide gas saturated with water vapor	...	38-77 (100-170)	60 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Hydrogen sulfide, water (extraction unit)	...	80-150 (176-302)	160 d	0.003 (0.1) max	Slight pitting	89
F51	S31803	...	Dry	4 max	20 (68)	...	Resistant	...	253
F51	S31803	...	Dry	4 max	100 (212)	...	Resistant	...	253
F51	S31803	...	Dry	4 max	400 max	...	Resistant	...	253
F51	S31803	...	Moist	4 max	400 max	...	Resistant	...	253



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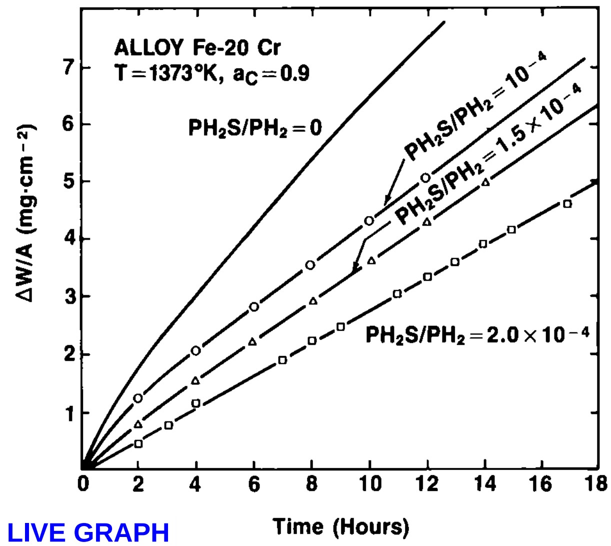
Carbon steel. Effect of temperature and hydrogen sulfide content on high-temperature H_2S/H_2 corrosion of carbon steel (gas oil desulfurizers). Source: J. Gutzeit, "High Temperature Sulfide Corrosion of Steels," *Process Industries Corrosion—The Theory and Practice*, National Association of Corrosion Engineers, Houston, 1986.



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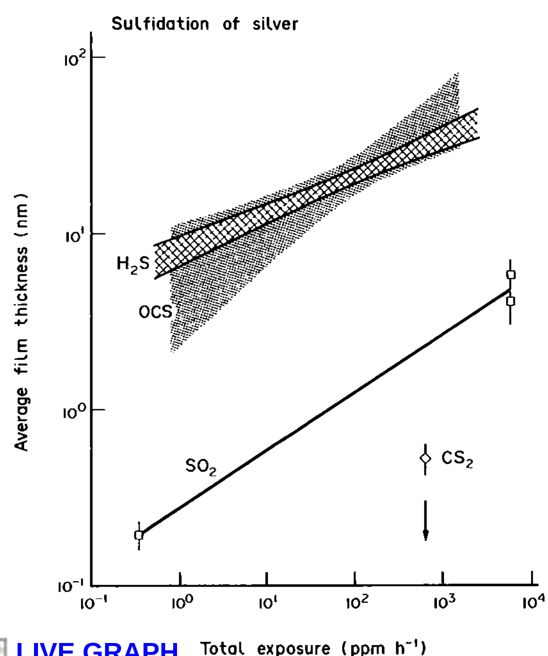
Fe-20Cr. Carburization kinetic data for Fe-20Cr alloy at 1373 K in the presence and absence of H_2S/H_2. Source: T.A. Ramanarayanan and D.J. Srolovitz, "Carburization Mechanisms of High Chromium Alloys," *Journal of the Electrochemical Society*, Vol 132, Sept 1875, 2272.



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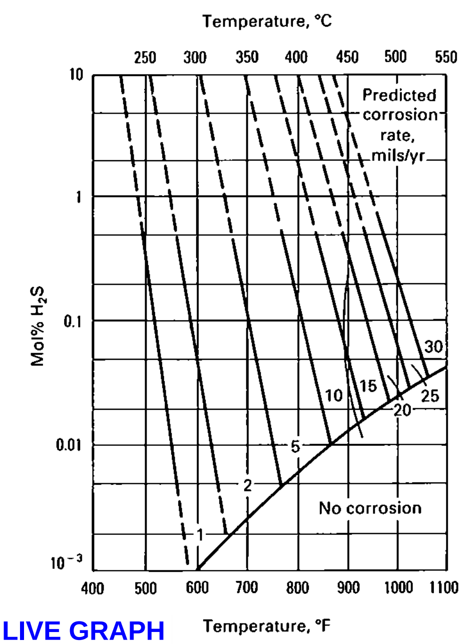
Silver. The thickness of the Ag_2S corrosion film as a function of total exposure to H_2S, OCS, SO_2 and CS_2. All exposures were made with RH = 92 ± 4%, t = 21 °C. Source: J.P. Franey, G.W. Kammlott, *et al.*, "The Corrosion of Silver by Atmospheric Sulfurous Gases," *Corrosion Science*, Vol 25, July 1985, 133.



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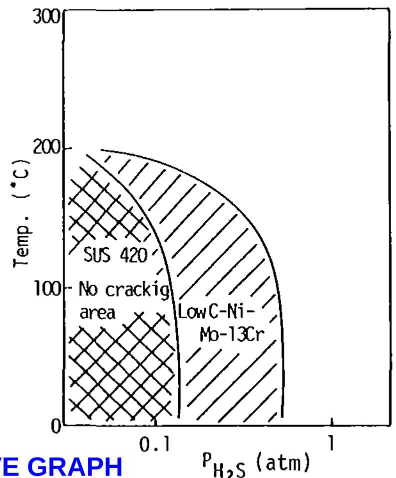
Stainless steel. Effect of temperature and hydrogen sulfide content on high-temperature H_2S/H_2 corrosion of 12% Cr stainless steel. Source: J. Gutzeit, "High Temperature Sulfide Corrosion of Steels," *Process Industries Corrosion—The Theory and Practice,* National Association of Corrosion Engineers, Houston, 1986.



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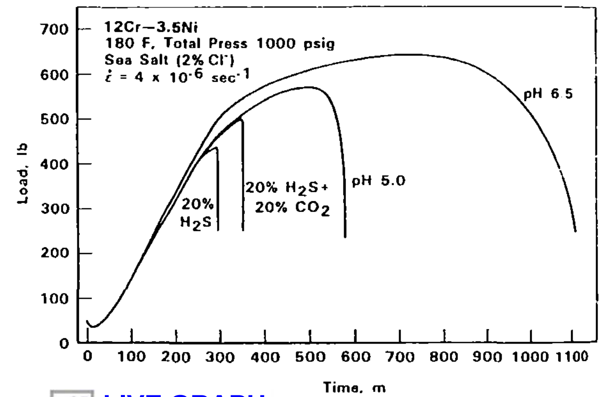
Stainless steel. No cracking area in H_2S environment. Source: T. Kurisu, M. Kimura, *et al.*, "Corrosion Resistance of Low C-Ni-13Cr Stainless Steels in CO_2/H_2O Environments," *Transactions of the Iron and Steel Institute of Japan*, Vol 25, April 1985, B-133.



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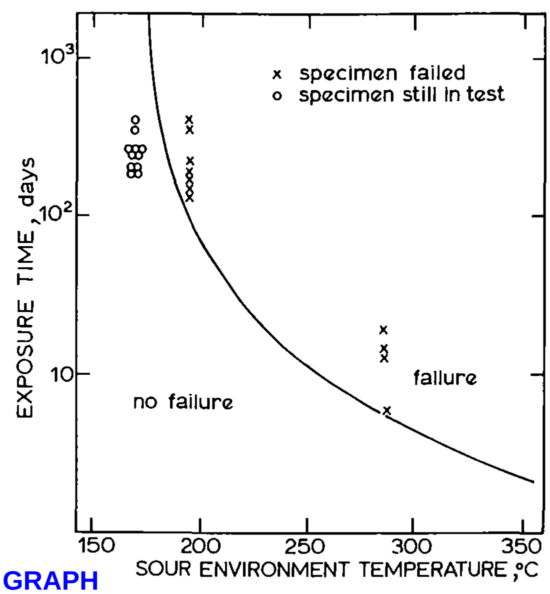
Stainless steel. Load vs. time-to-failure in slow strain rate tests at 82 °C (180 °F) in sea salt brine in the presence and absence of active gases. Source: A.K. Agrawal and W.N. Stiegelmeyer, "Corrosion and Cracking Behavior of a Martensitic 12Cr-3.5Ni-Fe Alloy in Simulated Sour Gas Environments, *Materials Performance*, Vol 26, Mar 1987, 24-29.



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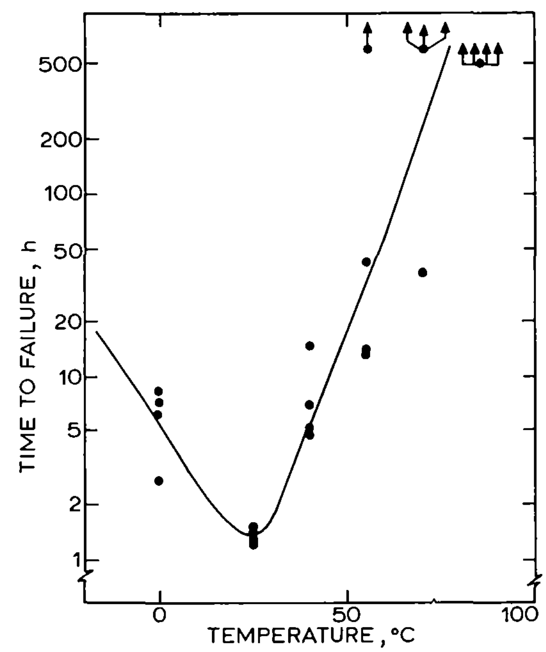
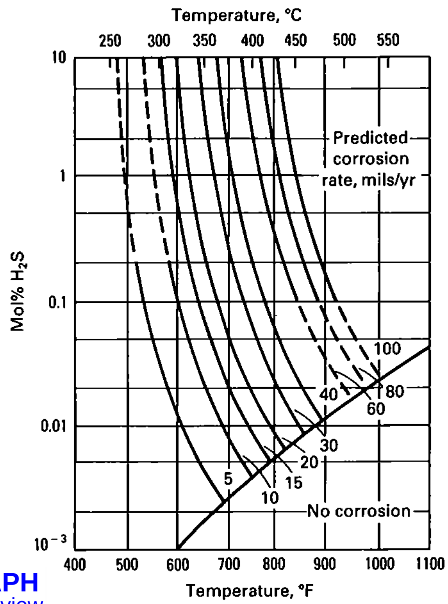
Hastelloy C-276. Stress-corrosion cracking behavior of Hastelloy C-276 versus testing temperature for specimens heat treated at 260 °C for 250 h. Environment: 25% sodium chloride, 0.5% acetic acid, and 1 g/L of sulfur and hydrogen sulfide. Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.



High-strength low-alloy steel. Time to failure for sulfide stress cracking versus temperature, showing minimum resistance at ~25 °C for a high-strength low-alloy steel (C-Mn composition). Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.



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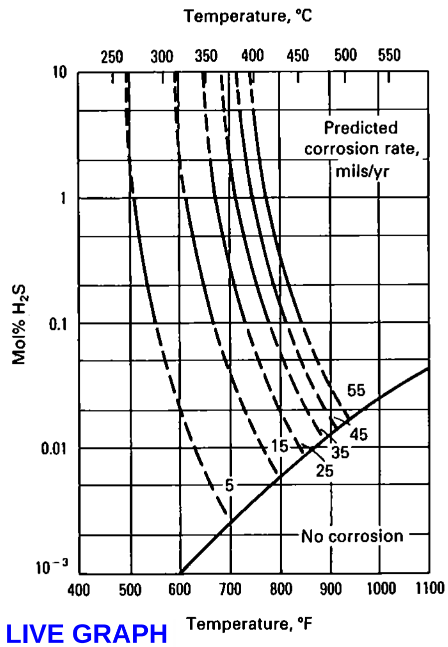
Low-alloy steel. Effect of temperature and hydrogen sulfide content on high-temperature H_2S/H_2 corrosion of 5Cr-0.5Mo steel (gas oil desulfurizers). Source: J. Gutzeit, "High Temperature Sulfide Corrosion of Steels," *Process Industries Corrosion—The Theory and Practice*, National Association of Corrosion Engineers, Houston, 1986.



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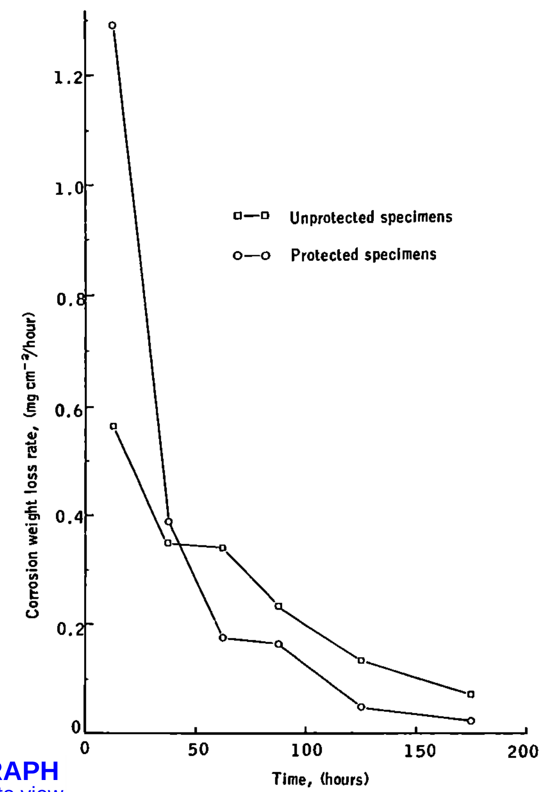
Alloy steel. Effect of temperature and hydrogen sulfide content on high-temperature H_2S/H_2 corrosion of 9Cr-1Mo steel (gas oil desulfurizers). Source: J. Gutzeit, "High Temperature Sulfide Corrosion of Steels," *Process Industries Corrosion—The Theory and Practice*, National Association of Corrosion Engineers, 1986.



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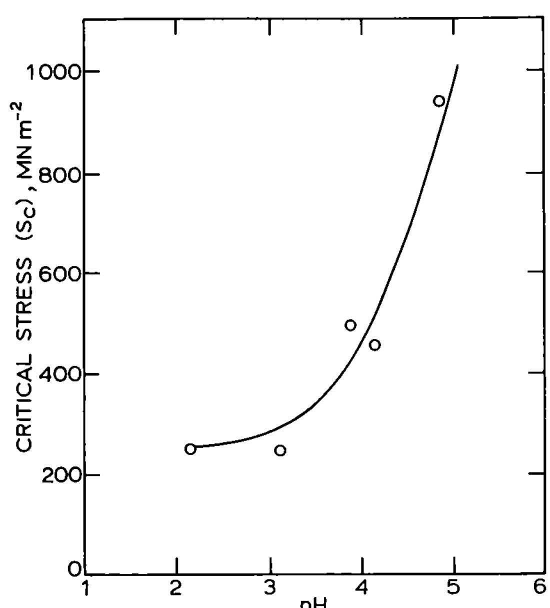
Low-alloy steel. The effect of FEP/MoS_2 coating on corrosion weight loss rate of EN 42 steel in NACE solution with H_2S bubbling continuously at 60 °C. Source: A.C.C. Tseung, T. Sriskandarajah, *et al.*, "A Method for the Inhibition of Sulphide Stress Corrosion Cracking in Steel. I. Electrochemical Aspects," *Corrosion Science*, Vol 25, June 1985, 390.



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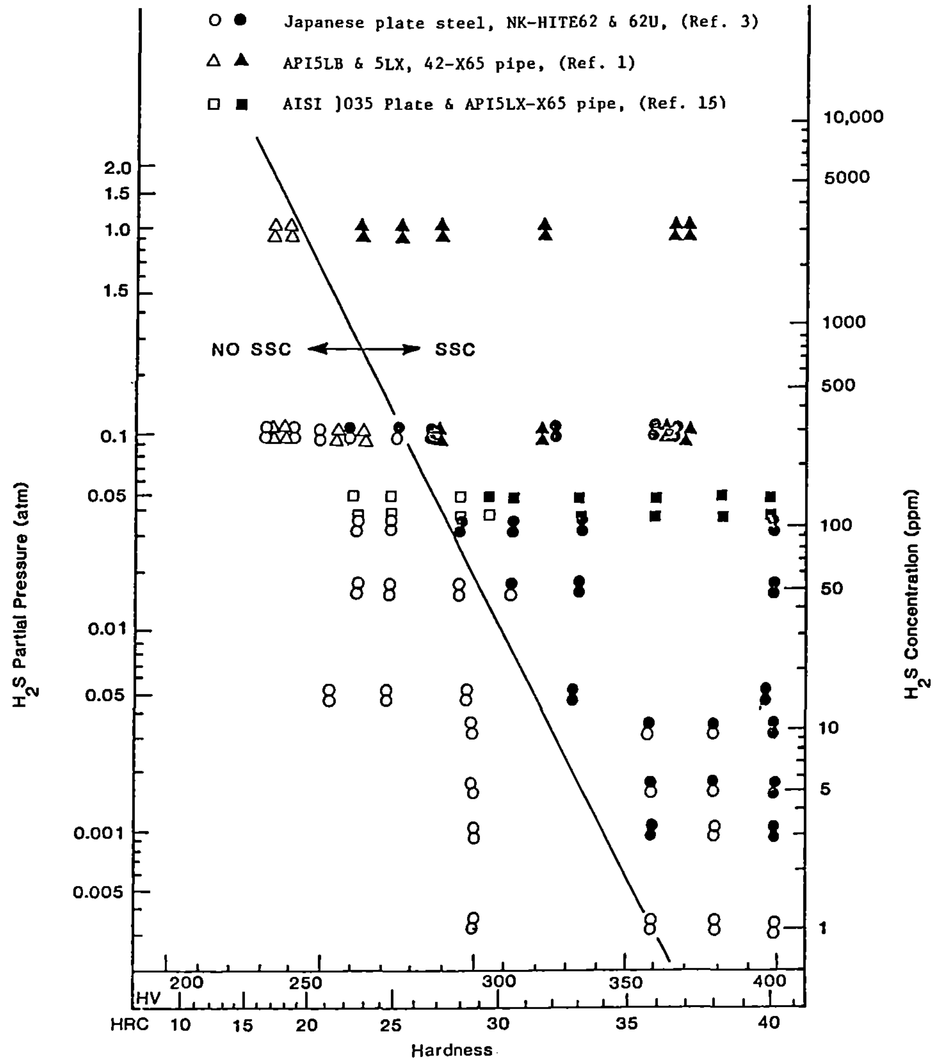
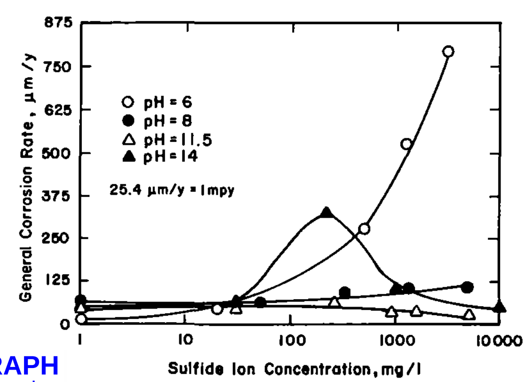
API casing steel. Effect of pH on sulfide stress cracking resistance of an API casing steel (C-Mn composition). Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.



Steels. Relationship between hydrogen sulfide concentration, partial pressure, and hardness in the heat-affected zone. Source: A. Omar *et al.,* "Corrosion/81," Paper No. 237, National Association of Corrosion Engineers, Houston, 1981.



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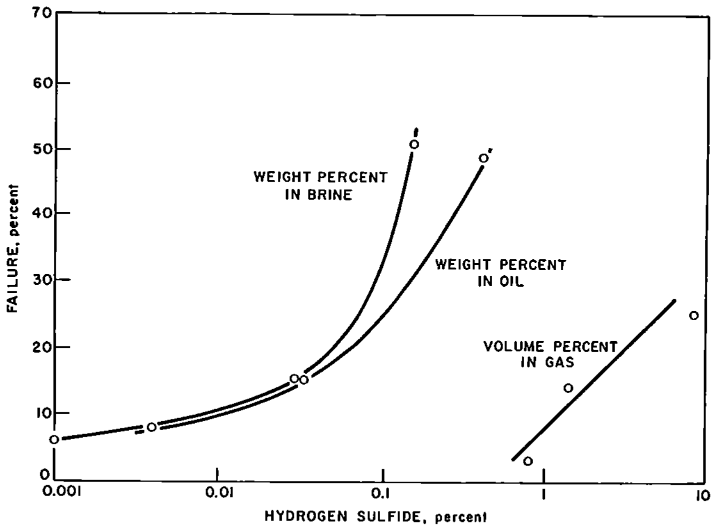
1040 steel. General corrosion rate versus sulfide ion concentration of 1040 steel in aqueous solutions of varying pH. Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.



Steels. Effect of hydrogen sulfide concentration on frequency of cracking of 112 to 128 ksi yield strength steels in sour crude oils. Source: A. Omar *et al.*, "Corrosion/81," Paper No. 237, National Association of Corrosion Engineers, Houston, 1981.

LIVE GRAPH
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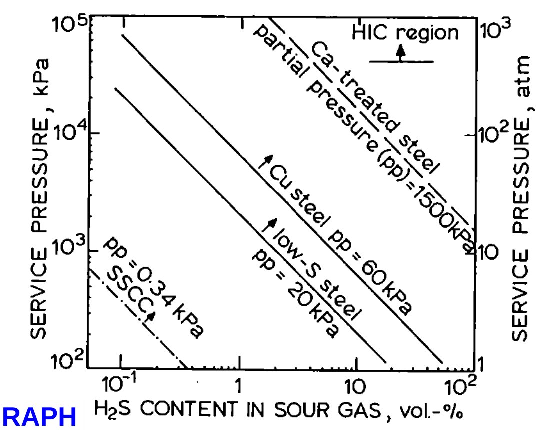

LIVE GRAPH
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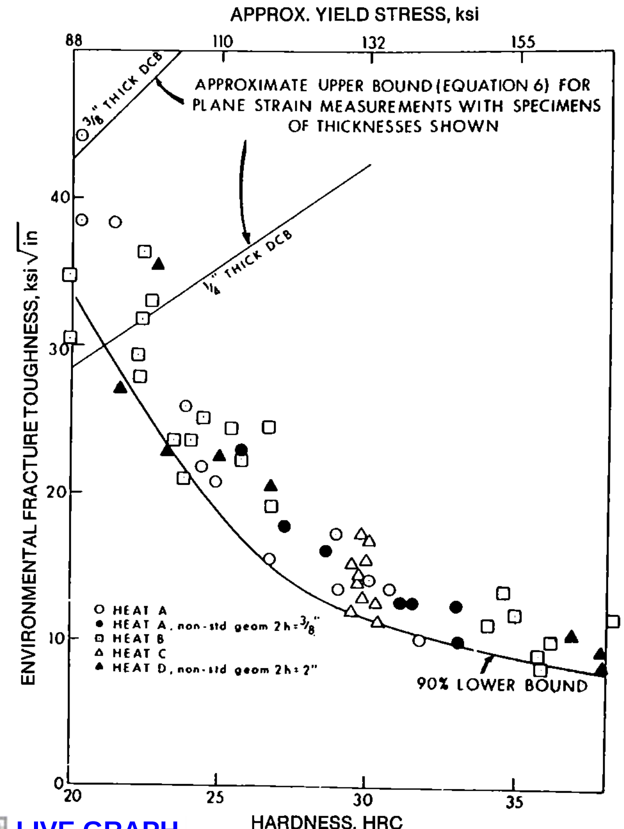
Steels. Critical hydrogen sulfide concentration for stepwise cracking for various linepipe steels. Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.



LIVE GRAPH
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4130 steel. Sulfide corrosion cracking resistance of laboratory quenched and tempered AISI 4130 steel. Source: R.D. Kane, Roles of H_2S in Behaviour of Engineering Alloys, The Institute of Metals and the American Society for Metals, 1985.

Hydroiodic Acid

Hydroiodic acid, HI, is a colorless solution of dissolved hydrogen iodide gas in water (commercially at a strength of 10% hydrogen iodide). It is prepared by the reaction of iodine and hydrosulfuric acid or by the reaction of phosphorus plus iodine plus water followed by distillation. Concentrated hydroiodic acid reacts with the oxygen of the air to form free iodine, which gives a brownish color to the solution. It also gives an idea of the reducing nature of this acid. It is an important reagent in organic chemistry and is used commercially in the preparation of iodides.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for cor-

rosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Niobium. Niobium is resistant to hydroiodic acid at all concentrations and at temperatures below 100 °C (212 °F).

Silver. Silver can only be exposed to dilute hydroiodic acid at room temperature.

Tin. Hot hydroiodic acid rapidly attacks tin.

Zirconium. Zirconium has a corrosion rate of less than 0.025 mm/yr (<1 mil/yr) in boiling 47% hydroiodic acid solutions. Results of pitting potential measurements indicate that zirconium has a lower pitting tendency in 1*N* hydroiodic acid than in 1*N* hydrochloric acid.

Corrosion Behavior of Various Metals and Alloys in Hydroiodic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	Specific gravity 1.75	Dilute	Room	...	0.05 (2) max	...	8
Iridium	...	...	Specific gravity 1.75	...	Room to 100 (212)	...	Resistant	...	29
Lead	L50045	...	...	10-50	24 (75)	...	1.3 (50) min	...	95
Osmium	...	...	Specific gravity 1.75	...	100 (212)	...	3.7 (148)	...	17
Palladium	P03980	...	Specific gravity 1.75	...	Room	...	66 (2600)	...	17
Rhodium	P05990	...	Specific gravity 1.75	...	100 (212)	...	Resistant	...	29
Ruthenium	...	...	...	60	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	Dilute	Room	...	0.25 (10) max	...	4
Silver	P07010	...	...	Dilute	Room	...	0.25 (10) max	...	4
Refractory metals and alloys									
Titanium, grade 2	R50400	...	...	10	Boiling	...	Resistant	...	32
Titanium, grade 2	R50400	...	...	57	25 (75)	...	0.15 (6)	...	32

Hydroxylamine Sulfate

Also hydroxylammonium sulfate, or HS, $(NH_2OH)_2 \cdot H_2SO_4$ is colorless crystals that are soluble in water and slightly soluble in alcohol. The solution has a corrosive action on the skin. Used as a reducing agent, photographic developer, purification agent for aldehydes and ketones, chemical synthesis, textile chemical, oxidation inhibitor for fatty acids, catalyst, in biological and biochemical research, for making oximes for paints and varnishes, and rustproofing.

Corrosion Behavior of Various Metals and Alloys in Hydroxylamine Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Hydroxylamine Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253

Hypochlorites

Hypochlorites are compounds containing the ion ClO_3^- that are formed when chlorine reacts with an alkali. The ClO_3^- ion is an oxidizing agent, and these alkaline salts are among the most corrosive. Hypochlorite salts include those of sodium, calcium, lithium, strontium, and barium, although sodium hypochlorite enjoys the most applications. Sodium hypochlorite is sold in two strengths, the household bleach strength of 5.25% and the commercial bleach strength of 13%. "Liquid chlorine" refers to the 10% solution used in treating swimming pools. Hypochlorite solutions are used for bleaching pulp, odor control, waste treatment/disposal, and water purification. Hypochlorite solutions decompose to release chlorine. This decomposition rate depends on concentration, temperature, pH, ionic strength, light, and the presence of trace metal contaminants such as cobalt, nickel, and copper that act as catalysts.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Nickel. Alkaline solutions containing hydrogen peroxide do not affect Alloy 600.

Platinum. When air is present, hypochlorite solutions attack platinum.

Tantalum. Only strong alkaline hypochlorite solutions affect tantalum.

Titanium. Titanium has excellent resistance to ClO_3^- compounds.

Corrosion Behavior of Various Metals and Alloys in Hypochlorites

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94

Hypochlorous Acid

Hypochlorous acid, HOCl, is a weak, unstable acid existing only in solution. Hypochlorous acid decomposes upon standing. The rate of decomposition depends on the concentration, pH, exposure to light, and the presence of contaminants that act as catalysts, for example, cobaltous hydroxide. Hypochlorous acid is a powerful oxidizing agent and is used in bleaching operations. The compound may be prepared by the reaction of chlorine monoxide and water, sodium hypochlorite and an acid, or chlorine with an aqueous suspension of mercuric oxide.

Material Summaries

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Tantalum. Tantalum is not attacked by hypochlorous acid at ordinary temperatures.

Titanium. Titanium alloys generally are highly resistant to attack over a wide range of concentrations and temperatures.

Corrosion Behavior of Various Metals and Alloys in Hypochlorous Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	...	Room	...	Poor	...	4
Refractory metals and alloys									
Titanium	...	...	Plus ClO and Cl_2 gases	17	38 (100)	...	Resistant	...	90

Iodine

Iodine, I, is a nonmetallic element with an orthorhombic crystal structure, a violet to black color, and a melting point of 114 °C (237 °F). This poisonous element sublimes readily and is easily purified in this manner. It is insoluble in water, but is soluble in common solvents such as alcohol, ether, and carbon tetrachloride. Iodine is used as a germicide, an antiseptic, in dyes, tinctures, and pharmaceuticals. It is also used in the production of vanadium metal in the McKechnie-Seybolt process, which is the reduction of vanadium pentoxide in the presence of iodine. Iodine is used in a similar manner in the production of high-purity zirconium.

For many years, iodine tincture (3% to 7% dissolved in ethyl alcohol) has been an important antiseptic. The commercial tinctures also usually contain 5% potassium iodide to provide stability. This form produces a mild burning of the skin and stains both skin and fabrics. A milder preparation is available in which about 2% iodine is contained in an oil-water emulsion which also contains lecithin.

Corrosion Behavior of Various Metals and Alloys in Iodine

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Dry solid	...	20 (68)	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92

(Continued)

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Miscellaneous									
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	...	Room	...	Poor	...	4
Refractory metals and alloys									
Titanium	...	...	Plus ClO and Cl_2 gases	17	38 (100)	...	Resistant	...	90

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Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Dry solid	...	20 (68)	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Iodine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	5% in alcohol	...	22 (72)	...	Poor	...	250
Gold	P00016	...	Wet or dry	...	22 (72)	...	.05 (2)	...	250
Gold	P00016	...	Wet or dry	...	50 (120)	...	Poor	...	250
Iridium	...	...	50 g/L in alcohol	...	22 (72)	...	.003 (0.1) max	...	250
Iridium	...	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Iridium	...	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Magnesium	...	...	Dry crystals	100	Room	...	Resistant	...	119
Osmium	...	...	Dry	...	22 (72)	...	.25 (10)	...	250
Platinum	P04995	...	50 g/L in alcohol	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	30 g/L in alcohol	...	22 (72)	...	0.25 (10)	...	250
Rhodium	P05990	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Rhodium	P05990	...	Moist	...	22 (72)	...	0.25 (10)	...	250
Ruthenium	...	...	50 g/L in alcohol	...	22 (72)	...	1.0 (40)	...	250
Ruthenium	...	...	Dry	...	22 (72)	...	.003 (0.1) max	...	250
Ruthenium	...	...	Moist	...	22 (72)	...	.003 (0.1) max	...	250
Silver	P07010	...	Dry	...	50 (120)	...	Poor	...	250
Silver	P07010	...	Moist	...	50 (120)	...	Poor	...	250
Nickel and alloys									
Alloy 825	N08825	...	Soap processing; field or plant test; no aeration; no agitation. Plus 90% nonionic detergent, some hydrochloric acid	10	22 (72)	90 d	0.003 (0.1)	...	89
Alloy 825	N08825	...	Soap processing; field or plant test; no aeration; rapid agitation. Plus 11% isopropyl alcohol, 2% hydrochloric acid, remainder nonionic detergent	9.3	22 (72)	90 d	0.10 (3.9)	...	89
Refractory metals and alloys									
Titanium	...	...	Dry or moist gas	...	25 (77)	...	0.1 (4)	...	90
Titanium	...	...	In alcohol	Saturated	Room	...	...	Pitted	90
Titanium	...	...	In H_2O + KI	...	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	Moist	...	20 (68)	...	Good	Pitting	253
301	S30100	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
302	S30200	...	Dry	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	Moist	...	20 (68)	...	Good	Pitting	253
302	S30200	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Questionable	Pitting	253
303	S30300	...	Moist	...	20 (68)	...	Good	Pitting	253
303	S30300	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
303	S30300	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
304	S30400	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Moist	...	20 (68)	...	Good	Pitting	253
304	S30400	...	Research lab test; no aeration; no agitation. Pressure 400 mm Hg	...	450 (842)	...	3 (120)	...	89
304	S30400	...	Soap processing; field or plant test; no aeration; no agitation. Plus 90% nonionic detergent, some hydrochloric acid.	10	22 (72)	90 d	0.05 (2)	...	89
304	S30400	...	Soap processing; field or plant test; no aeration; rapid agitation. Plus 11% isopropyl alcohol, 2% hydrochloric acid, remainder nonionic detergent	9.3	22 (72)	90 d	0.18 (7.1)	...	89
304	S30400	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
304L	S30403	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	Moist	...	20 (68)	...	Good	Pitting	253

(Continued)

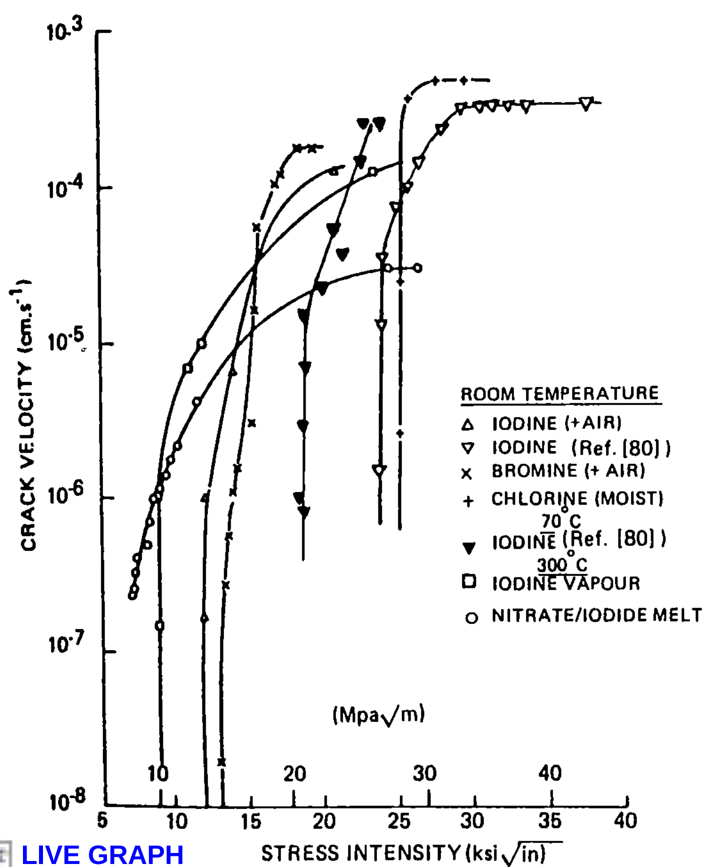
Corrosion Behavior of Various Metals and Alloys in Iodine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	Dry	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	Moist	...	20 (68)	...	Good	Pitting	253
304LN	S30453	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
316	S31600	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Moist	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Research lab test; no aeration; no agitation. Pressure 400 mm Hg	...	450 (842)	...	2.0 (81)	...	89
316	S31600	...	Soap processing; field or plant test; no aeration; no agitation. Plus 90% nonionic detergent, some hydrochloric acid	10	22 (72)	90 d	0.008 (0.3)	...	89
316	S31600	...	Soap processing; field or plant test; no aeration; rapid agitation. Plus 11% isopropyl alcohol, 2% hydrochloric acid, remainder nonionic detergent	9.3	22 (72)	90 d	0.06 (2.3)	...	89
316	S31600	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	Moist	...	20 (68)	...	Good	Pitting	253
316F	S31620	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Moist	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Moist	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	Dry	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	Moist	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
317L	S31703	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Moist	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	Dry	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Moist	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
321	S32100	...	Dry	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	Moist	...	20 (68)	...	Good	Pitting	253
321	S32100	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
329	S32900	...	Dry	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Moist	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
347	S34700	...	Dry	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	Moist	...	20 (68)	...	Good	Pitting	253
347	S34700	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
403	S40300	...	Dry	...	20 (68)	...	Resistant	Pitting	253
403	S40300	...	Moist	...	20 (68)	...	Questionable	Pitting	253
403	S40300	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
405	S40500	...	Dry	...	20 (68)	...	Resistant	Pitting	253
405	S40500	...	Moist	...	20 (68)	...	Questionable	Pitting	253
405	S40500	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
409	S40900	...	Dry	...	20 (68)	...	Resistant	Pitting	253
409	S40900	...	Moist	...	20 (68)	...	Questionable	Pitting	253
409	S40900	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
410	S41000	...	Moist	...	20 (68)	...	Questionable	Pitting	253
410	S41000	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
416	S41600	...	Dry	...	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Iodine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	Moist	...	20 (68)	...	Questionable	Pitting	253
416	S41600	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
420	S42000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
420	S42000	...	Moist	...	20 (68)	...	Questionable	Pitting	253
420	S42000	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
430	S43000	...	Dry	...	20 (68)	...	Resistant	Pitting	253
430	S43000	...	Moist	...	20 (68)	...	Questionable	Pitting	253
430	S43000	...	Tincture of Iodine	...	20 (68)	...	Questionable	Pitting	253
434	S43400	...	Dry	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	Moist	...	20 (68)	...	Good	Pitting	253
434	S43400	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253
Carpenter 20	...	...	Soap processing; field or plant test; no aeration; no agitation. Plus 90% nonionic detergent, some hydrochloric acid	10	22 (72)	90 d	0.005 (0.2)	...	89
Carpenter 20	...	...	Soap processing; field or plant test; no aeration; rapid agitation. Plus 11% isopropyl alcohol, 2% hydrochloric acid, remainder nonionic detergent	9.3	22 (72)	90 d	0.18 (7.3)	...	89
F51	S31803	...	Dry	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Moist	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	Tincture of Iodine	...	20 (68)	...	Good	Pitting	253



LIVE GRAPH
Click here to view

Zircaloy. Velocity versus stress intensity curves for Zircaloy in halogen vapors. Ref. 266

Lactic Acid

Lactic acid, $CH_3CHOHCOOH$, also known as 2-hydroxypropanoic acid, is a hygroscopic liquid that exists in three isometric forms. *l*-lactic acid is found in blood and animal tissue as a product of glucose and glycogen metabolism. *d*-lactic acid is obtained by fermentation of sucrose (corn refining). The racemic mixture is present in foods prepared by bacterial fermentation or prepared synthetically. Lactic acid is soluble in water, alcohol, and ether. It is used as a solvent, in manufacturing confectionery, and in medicine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 suffered mild attack (0.075 mm/yr, or 3 mils/yr) in aqueous solutions of lactic acid (0.05 to 80%) during laboratory tests. When the temperature was raised to 100 °C (212 °F), lactic acid became very corrosive, with the greatest rate occurring at 5% concentration.

Copper. Aluminum bronzes generally are suitable for service in lactic acid.

Zirconium. Zirconium resists corrosion in lactic acid.

Corrosion Behavior of Various Metals and Alloys in Lactic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Gold	P00016	...	...	All	Boiling	...	0.05 (2) max	...	8
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet	...	10	80 (175)	7 d	0.003 (0.1) max	No pitting	44

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lactic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 601	N06601	...	...	10	80 (176)	7 d	0.9 (36)	...	64
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Nickel 200	N02200	...	In vacuum evaporator	10-22	54 (130)	...	1.3 (51)	...	44
Nickel 200	N02200	...	Lab immersion test	2	Room	...	0.052 (2.1)	...	44
Nickel 200	N02200	...	Lab immersion test	85	Room	...	0.067 (2.7)	...	44
Nickel 200	N02200	...	Liquid phase in vacuum evaporator	To 85	49-82 (120-180)	...	0.25 (10)	...	44
Nickel 200	N02200	...	Vapor phase in vacuum evaporator	To 85	49-82 (120-180)	...	0.27 (11)	...	44
Refractory metals and alloys									
40Co-20Cr-15Ni-7Mo	...	...	...	10	104 (219)	50 h	Resistant	...	54
Niobium	R04210	...	...	10-85	Boiling	...	0.025 (1.0)	...	2
Titanium	...	...	...	10-85	100 (212)	...	0.13 (5)	...	90
Titanium	...	...	...	10	Boiling	...	0.13 (5)	...	90
Titanium, unalloyed	...	...	...	85-100	100 (212)	...	0.01 (0.4)	...	218
Zr702	R60702	...	...	10-100	148 (298)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	10-85	35 (95 to boiling)	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	1.5	20 (68)	...	Resistant	...	253
301	S30100	...	...	1.5	Boiling	...	Resistant	...	253
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Good	...	253
301	S30100	...	...	80	20 (68)	...	Resistant	...	253
301	S30100	...	...	80	Boiling	...	Questionable	...	253
301	S30100	...	...	Concentrated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Concentrated	Boiling	...	Questionable	...	253
302	S30200	...	...	1.5	20 (68)	...	Resistant	...	253
302	S30200	...	...	1.5	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Good	...	253
302	S30200	...	...	80	20 (68)	...	Resistant	...	253
302	S30200	...	...	80	Boiling	...	Questionable	...	253
302	S30200	...	...	Concentrated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Concentrated	Boiling	...	Questionable	...	253
303	S30300	...	...	1.5	20 (68)	...	Resistant	...	253
303	S30300	...	...	1.5	20 (68)	...	Resistant	...	253
303	S30300	...	...	1.5	Boiling	...	Good	...	253
303	S30300	...	...	1.5	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Poor	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	80	20 (68)	...	Good	...	253
303	S30300	...	...	80	20 (68)	...	Resistant	...	253
303	S30300	...	...	80	Boiling	...	Questionable	...	253
303	S30300	...	...	80	Boiling	...	Questionable	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Good	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	Boiling	...	Questionable	...	253
303	S30300	...	...	Concentrated	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lactic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	1.5	20 (68)	...	Resistant	...	253
304	S30400	...	...	1.5	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Good	...	253
304	S30400	...	...	80	20 (68)	...	Resistant	...	253
304	S30400	...	...	80	Boiling	...	Questionable	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Concentrated	Boiling	...	Questionable	...	253
304	S30400	...	No activation	20	Boiling	24 h	1.825 (73)	...	52
304L	S30403	...	...	1.5	20 (68)	...	Resistant	...	253
304L	S30403	...	...	1.5	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Good	...	253
304L	S30403	...	...	80	20 (68)	...	Resistant	...	253
304L	S30403	...	...	80	Boiling	...	Questionable	...	253
304L	S30403	...	...	Concentrated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Concentrated	Boiling	...	Questionable	...	253
304LN	S30453	...	...	1.5	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	1.5	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Good	...	253
304LN	S30453	...	...	80	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	80	Boiling	...	Questionable	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	Boiling	...	Questionable	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	1.5	20 (68)	...	Resistant	...	253
316	S31600	...	...	1.5	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	80	20 (68)	...	Resistant	...	253
316	S31600	...	...	80	Boiling	...	Good	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	Boiling	...	Good	...	253
316	S31600	...	No activation	20	Boiling	24 h	0.0025 (0.1)	...	52
316F	S31620	...	...	1.5	20 (68)	...	Resistant	...	253
316F	S31620	...	...	1.5	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Good	...	253
316F	S31620	...	...	80	20 (68)	...	Resistant	...	253
316F	S31620	...	...	80	Boiling	...	Questionable	...	253
316F	S31620	...	...	Concentrated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Concentrated	Boiling	...	Questionable	...	253
316L	S31603	...	...	1.5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	1.5	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	80	20 (68)	...	Resistant	...	253
316L	S31603	...	...	80	Boiling	...	Good	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lactic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	1.5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	1.5	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	80	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	80	Boiling	...	Good	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	Boiling	...	Good	...	253
316Ti	S31635	...	...	1.5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	1.5	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	80	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	80	Boiling	...	Good	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	Boiling	...	Good	...	253
317L	S31703	...	...	1.5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	1.5	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	80	20 (68)	...	Resistant	...	253
317L	S31703	...	...	80	Boiling	...	Good	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Concentrated	Boiling	...	Good	...	253
317LN	S31725	...	...	1.5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	1.5	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	80	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	80	Boiling	...	Good	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	Boiling	...	Good	...	253
321	S32100	...	...	1.5	20 (68)	...	Resistant	...	253
321	S32100	...	...	1.5	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Good	...	253
321	S32100	...	...	80	20 (68)	...	Resistant	...	253
321	S32100	...	...	80	Boiling	...	Questionable	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Concentrated	Boiling	...	Questionable	...	253
329	S32900	...	...	1.5	20 (68)	...	Resistant	...	253
329	S32900	...	...	1.5	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	80	20 (68)	...	Resistant	...	253
329	S32900	...	...	80	Boiling	...	Good	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	Boiling	...	Good	...	253
347	S34700	...	...	1.5	20 (68)	...	Resistant	...	253
347	S34700	...	...	1.5	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Good	...	253

(Continued)

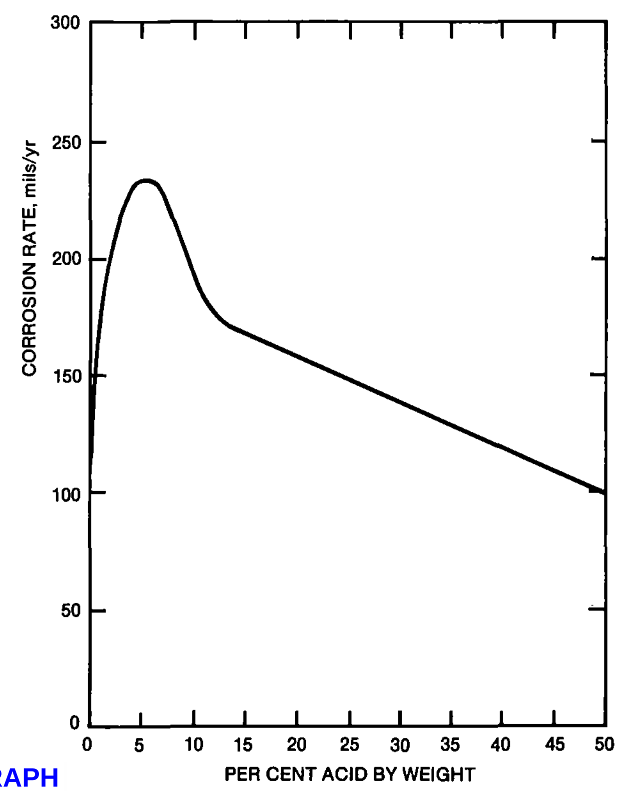
Corrosion Behavior of Various Metals and Alloys in Lactic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	...	80	20 (68)	...	Resistant	...	253
347	S34700	...	...	80	Boiling	...	Questionable	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Concentrated	Boiling	...	Questionable	...	253
403	S40300	...	...	1.5	20 (68)	...	Good	...	253
403	S40300	...	...	10	20 (68)	...	Good	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	...	80	20 (68)	...	Good	...	253
403	S40300	...	...	80	Boiling	...	Poor	...	253
403	S40300	...	...	Concentrated	20 (68)	...	Good	...	253
403	S40300	...	...	Concentrated	Boiling	...	Poor	...	253
405	S40500	...	...	1.5	20 (68)	...	Good	...	253
405	S40500	...	...	10	20 (68)	...	Good	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	...	80	20 (68)	...	Good	...	253
405	S40500	...	...	80	Boiling	...	Poor	...	253
405	S40500	...	...	Concentrated	20 (68)	...	Good	...	253
405	S40500	...	...	Concentrated	Boiling	...	Poor	...	253
409	S40900	...	...	1.5	20 (68)	...	Good	...	253
409	S40900	...	...	10	20 (68)	...	Good	...	253
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	...	80	20 (68)	...	Good	...	253
409	S40900	...	...	80	Boiling	...	Poor	...	253
409	S40900	...	...	Concentrated	20 (68)	...	Good	...	253
409	S40900	...	...	Concentrated	Boiling	...	Poor	...	253
410	S41000	...	...	10	21 (70)	...	Poor	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	1.5	20 (68)	...	Good	...	253
410	S41000	...	...	10	20 (68)	...	Good	...	253
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	...	80	20 (68)	...	Good	...	253
410	S41000	...	...	80	Boiling	...	Poor	...	253
410	S41000	...	...	Concentrated	20 (68)	...	Good	...	253
410	S41000	...	...	Concentrated	Boiling	...	Poor	...	253
416	S41600	...	...	1.5	20 (68)	...	Good	...	253
416	S41600	...	...	10	20 (68)	...	Good	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	...	80	20 (68)	...	Good	...	253
416	S41600	...	...	80	Boiling	...	Poor	...	253
416	S41600	...	...	Concentrated	20 (68)	...	Good	...	253
416	S41600	...	...	Concentrated	Boiling	...	Poor	...	253
420	S42000	...	...	1.5	20 (68)	...	Good	...	253
420	S42000	...	...	10	20 (68)	...	Good	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	...	80	20 (68)	...	Good	...	253
420	S42000	...	...	80	Boiling	...	Poor	...	253
420	S42000	...	...	Concentrated	20 (68)	...	Good	...	253
420	S42000	...	...	Concentrated	Boiling	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Poor	...	121
430	S43000	...	...	1.5	20 (68)	...	Resistant	...	253
430	S43000	...	...	1.5	Boiling	...	Good	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	Boiling	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lactic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	80	20 (68)	...	Good	...	253
430	S43000	...	...	80	Boiling	...	Questionable	...	253
430	S43000	...	...	Concentrated	20 (68)	...	Good	...	253
430	S43000	...	...	Concentrated	Boiling	...	Questionable	...	253
434	S43400	...	...	1.5	20 (68)	...	Resistant	...	253
434	S43400	...	...	1.5	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	80	20 (68)	...	Resistant	...	253
434	S43400	...	...	80	Boiling	...	Questionable	...	253
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Concentrated	Boiling	...	Questionable	...	253
444	S44400	...	No activation	20	Boiling	24 h	0.005 (0.2)	...	52
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	...	1.5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	1.5	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	80	20 (68)	...	Resistant	...	253
F51	S31803	...	...	80	Boiling	...	Good	...	253
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	Boiling	...	Good	...	253



LIVE GRAPH
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Aluminum. Effect of lactic acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 33.

Lead Acetate

Lead acetate, $Pb(C_2H_3O_2)_2 \cdot 3H_2O$ is usually white crystals or flakes, although commercial grades are frequently brown or gray lumps, has a sweetish taste, is poisonous, and absorbs carbon dioxide when exposed to air. Soluble in water, slightly soluble in alcohol, and freely soluble in glycerol; decomposes at 280 °C and loses water at 75 °C. Derivation is by the action of acetic acid on litharge or thin lead plates. Used in the manufacture of varnishes and pigments.

Corrosion Behavior of Various Metals and Alloys in Lead Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	Boiling	...	Good	...	253
405	S40500	...	...	All concentrations	Boiling	...	Good	...	253
409	S40900	...	...	All concentrations	Boiling	...	Good	...	253
410	S41000	...	...	All concentrations	Boiling	...	Good	...	253
416	S41600	...	...	All concentrations	Boiling	...	Good	...	253
420	S42000	...	...	All concentrations	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lead Acetate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Lead Nitrate

Lead nitrate, $Pb(NO_3)_2$, is white crystals, soluble in water and alcohol. Derivation is by the action of nitric acid on lead. Used as lead salts, mordant in dyeing and printing calico, matches, mordant for staining mother of pearl, oxidizer in the dye industry, sensitizer in photography, explosives, tanning, process engraving, and lithography.

Corrosion Behavior of Various Metals and Alloys in Lead Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Good	...	253
405	S40500	...	...	...	20 (68)	...	Good	...	253
409	S40900	...	...	...	20 (68)	...	Good	...	253
410	S41000	...	...	...	20 (68)	...	Good	...	253
416	S41600	...	...	...	20 (68)	...	Good	...	253
420	S42000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Linseed Oil

Also known as flaxseed oil, linseed oil is golden yellow, amber, or brown drying oil with a peculiar odor and bland taste. Iodine value 177, saponification value 189-195, acid number (max.) 4 (ASTM D 234-48), polymerizes on exposure to air. Soluble in ether, chloroform, carbon disulfide, and turpentine; slightly soluble in alcohol, spontaneous heating. Combustible. Chief constituents are glycerides of linolenic, oleic, linoleic, and saturated fatty acids. The drying property is due to the linoleic and linolenic groups. Derivation is from seeds of the flax plant *Linum usitatissimum* by expression or solvent extraction. Various refining and bleaching methods are used. The grades of linseed oil are raw, boiled, double-boiled, blown, varnish makers' and refined. Used in paints, varnishes, oilcloth, putty, printing inks, core oils, linings, and packings, alkyd resins, soap, and pharmaceuticals.

Corrosion Behavior of Various Metals and Alloys in Linseed Oil

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
301	S30100	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
302	S30200	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
302	S30200	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
303	S30300	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
303	S30300	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
303	S30300	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
304	S30400	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
304	S30400	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
304L	S30403	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
304LN	S30453	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
316	S31600	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
316	S31600	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
316F	S31620	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
316L	S31603	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
316LN	S31653	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
316Ti	S31635	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
317L	S31703	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
317LN	S31725	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
321	S32100	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
321	S32100	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
329	S32900	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
329	S32900	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
347	S34700	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
347	S34700	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
403	S40300	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
405	S40500	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
409	S40900	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
410	S41000	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Linseed Oil (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
420	S42000	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
430	S43000	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
434	S43400	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
434	S43400	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253
F51	S31803	...	Plus 3% H_2SO_4	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Plus 3% H_2SO_4	...	200 (392)	...	Resistant	...	253

Liquid Metals

The various types of corrosion reactions (direct dissolution, corrosion product formation, elemental transfer, alloying, compound reduction, and environmentally assisted cracking) must be considered in materials selection for liquid-metal containment. In many cases, particularly at low temperature or with less aggressive liquids, liquid-metal corrosion is not an important factor, and many materials, both metals and ceramics, would suffice. Under more severe conditions, however, an understanding of the various types of liquid-metal corrosion is necessary to select or develop a compatible containment material. For example, for applications in high-temperature molten lithium, most oxides would be unstable with respect to this liquid metal, low-chromium steels would decarburize, and alloys containing large amounts of nickel or manganese would suffer extensive preferential dissolution and irregular attack. Materials selection would then be limited to higher chromium ferritic/martensitic steels or high-purity refractory metals and alloys.

Because two or more concurrent corrosion reactions are possible, and because consideration of all of the applicable materials consequences may lead to opposite strategies, materials selection for liquid-metal environments can become quite complex and may require optimization of several factors rather than minimization of any particular one. In addition, an assessment of the suitability of a given material for liquid-metal service must be based on the knowledge of its total corrosion response.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons

Unalloyed cast iron is used as a melting crucible for such low-melting metals as lead, zinc, cadmium, magnesium, and aluminum.

Carbon and Low-Alloy Steels

Plain carbon steels are not satisfactory for long-term containment of molten aluminum. Low-carbon steels have poor resistance to attack by liquid antimony. Low-alloy steels have good resistance to liquid bismuth at temperatures up to 700 °C (1290 °F). Bismuth alloys are more aggressive. Low-alloy steels exhibit good serviceability in liquid cadmium at temperatures up to 700 °C (1290 °F). One of the most aggressive of all liquid metals that cannot be contained by carbon or low-alloy steels at elevated temperatures is gallium. Carbon and low-alloy steels have poor resistance to molten indium. Low-alloy steels are resistant to molten lead at temperatures up to 600 °C (1110 °F), but are attacked more aggressively by lead-base alloys.

Although plain carbon steels are virtually unattacked by mercury under nonflowing or isothermal conditions, the presence of either a temperature gradient or liquid flow can lead to drastic attack. The corrosion mechanism appears to be one of dissolution, with the rate of attack increasing rapidly with temperatures above 500 °C (930 °F). Alloy additions of chromium, titanium, silicon, and molybdenum, alone or in combination, provide resistance to 600 °C (1110 °F). Where applicable, the attack of ferrous alloys by mercury can be reduced to negligible amounts by the addition of 10 ppm Ti to the mercury; this raises the useful limit of operating temperatures to 650 °C (1200 °F). Additions of metal with a higher affinity for oxygen than titanium, such as magnesium, may be required to prevent oxidation of the titanium and loss of the inhibitive action.

Plain carbon and low-alloy steels are generally suitable for long-term use in sodium and sodium-potassium alloys at temperatures to 450 °C (840 °F). Beyond these temperatures, stainless steels are required. Low-alloy steels are resistant to molten tin only at temperatures up to 150 °C (300 °F). Alloys of tin are more aggressive. Most engineering metals and alloys show poor resistance to molten zinc, and carbon steels are no exception.

Stainless Steels

The 18-8 stainless steels are highly resistant to liquid sodium or sodium-potassium alloys. Mass transfer is not expected up to 540 °C (1000 °F) and remains at moderately low levels up to 870 °C (1600 °F). Accelerated attack of stainless steels in liquid sodium occurs with oxygen contamination, with a noticeable effect occurring at about 0.02% oxygen by weight.

Exposure to molten lead under dynamic conditions often results in mass transfer in common stainless alloy systems. Particularly severe corrosion can occur in strongly oxidizing conditions.

Stainless steels are generally attacked by molten aluminum, zinc, antimony, bismuth, cadmium, and tin.

Niobium

Niobium resists attack in many liquid metals to relatively high temperatures. These include bismuth below 510 °C (950 °F), gallium below 400 °C (750 °F), lead below 850 °C (1560 °F), lithium below 1000 °C (1830 °F), mercury below 600 °C (1110 °F), sodium, potassium, and sodium-potassium alloys below 1000 °C (1830 °F), thorium-magnesium eutectic below 850 °C (1560 °F), uranium below 1400 °C (2550 °F), and zinc below 450 °C (840 °F). The presence of excessive amounts of nonmetallic impurities (for example, gases) may reduce the resistance of niobium to these liquid metals.

Because liquid metals are excellent heat transfer media, they can be used in very compact thermal systems, such as the fast breeder reactor, reactors for space vehicles, and fusion reactors. Niobium is a serious candidate as a material for high-efficiency reactors.

Niobium resists attack by sodium vapor at high temperatures and pressures. The Nb-1Zr alloy is used for the end caps in high-pressure sodium vapor lamps used for highway lighting.

Noble Metals

Gold. Gold is attacked by low-melting alloys, including mercury, sodium, potassium, lead, tin, bismuth, and iridium.

Silver. All the low-melting molten metals attack silver, including mercury, sodium, potassium, lead, tin, bismuth, and indium.

Platinum. A number of low-melting metals, including lead, tin, antimony, zinc, and arsenic, will readily alloy with and attack platinum at their melting temperatures. Low-melting phases are formed with silicon, phosphorus, bismuth, and boron, and salts or compounds of these metals can be detrimental at high temperatures under reducing conditions.

Iridium. Iridium shows excellent resistance to attack by a wide range of molten metals. Iridium is unattacked by gallium, lithium, potassium, sodium, indium, mercury, and bismuth at temperatures up to 200 °C (360 °F) above their respective melting points under an atmosphere of argon. It is only slowly attacked by molten lead, tellurium, cadmium, antimony, tin, calcium, silver, and gold. On the other hand, the metal is readily attacked by molten copper, aluminum, zinc, and magnesium.

Ruthenium. Ruthenium exhibits good resistance to attack by molten lithium, sodium, potassium, copper, silver, and gold when it is heated in an atmosphere of argon. No solution attack by these metals occurs up to 100 °C (212 °F) above their melting points, although grain-boundary penetration is observed with sintered and unworked ruthenium. Ruthenium is also resistant to attack by molten lead, and at temperatures up to 700 °C (1290 °F), attack by liquid bismuth is extremely slight. The solubility of ruthenium in bismuth at this temperature is 0.029%. At 1200 °C (2190 °F), it is 0.016%.

Ruthenium is also unattacked by mercury at temperatures up to 550 °C (1020 °F). Ruthenium is apparently unattacked at lower temperatures by gallium, but there is some attack at temperatures 400 °C (720 °F) above the melting point of gallium. Similarly, bismuth dissolves ruthenium very slowly at 700 °C (1290 °F), with the dissolution occurring uniformly at the ruthenium surface.

Ruthenium is attacked by molten aluminum or zinc at all temperatures above their melting points. This attack appears to consist of uniform dissolution of the surface and does not result in the formation of intermetallic compounds or grain-boundary penetration. On the other hand, attack by magnesium and antimony occurs with the formation of an intermetallic compound at the interface, which appears to have some protective value.

Rhodium. At temperatures 200 °C (392 °F) above their melting points, gold, silver, mercury, cesium, potassium, sodium, and gallium have negligible corrosive action on rhodium, but unlike iridium and ruthenium, rhodium is rapidly dissolved by lead and bismuth.

Tantalum

Tantalum and some tantalum-base alloys exhibit good resistance to many liquid metals. Such tantalum materials exhibit remarkable resistance to several liquid metals even to high temperatures (900 to 1100 °C, or 1650 to 2010 °F) in the absence of oxygen or nitrogen. The severity of attack on tantalum by liquid metals may be markedly increased by increasing temperature. Because operating temperatures somewhat in excess of 700 °C (1290 °F) are desirable in many cases, refractory metals, including tantalum and niobium, seem to be particularly promising materials of construction for containing liquid metals.

Liquid aluminum reacts rapidly with tantalum to form the stable compound aluminum (Al_3Ta). Liquid bismuth has little action on tantalum at temperatures below 1000 °C (1830 °F) and exerts no detrimental effects on the stress-rupture properties of tantalum at 815 °C (1500 °F), but it causes some intergranular attack at 1000 °C (1830 °F). Tantalum is only slightly attacked by calcium at 1200 °C (2190 °F). A crucible with a wall thickness of 0.15 mm (5.8 mils) was reduced to 0.13 mm (5.3 mils) after 12 days of exposure to calcium at 1200 °C (2190 °F).

Similar lack of corrosion resistance to cesium was found for tantalum as reported for niobium. Refluxing capsule tests indicated surface dissolution and severe attack after 720 h at 980 and 1370 °C (1800 and 2500 °F). The resistance of tantalum to molten gallium is considered to be good at temperatures to 450 °C (840 °F), but poor at temperatures above 600 °C (1110 °F). Tantalum is highly resistant to liquid lead at temperatures to 1000 °C (1830 °F), with a rate of attack of less than 0.025 mm/yr (1 mil/yr).

It exhibits no detrimental effects when stress-rupture tests are conducted in molten lead at 815 °C (1500 °F).

Tantalum possesses good resistance to molten lithium at temperatures up to 1000 °C (1830 °F). Its service ability with lithium is similar to that of niobium in that corrosion resistance depends on oxygen concentration. Tantalum metal will exhibit good corrosion resistance to lithium as long as the oxygen concentration of the tantalum is maintained below 100 to 200 ppm.

Specimens of T-111 and T-222 (Ta-9.6W-2.4Hf-0.01C) alloys, oxygen contaminated to 500 ppm and welded in argon, were exposed to lithium at 750 and 1200 °C (1380 and 2190 °F) for 100 h. Evaluation indicated no attack in the weld areas; however, intergranular penetration was observed in the base metal of both alloys. Heat treatment at 1315 °C (2400 °F) eliminated the attack. In addition, a method of inhibiting the corrosion of tantalum by liquid lithium at temperatures above 1000 °C (1830 °F) by the addition of 0.15 to 1.5 at.% Si to the lithium has been discussed.

In one investigation, simulated nuclear-fuel element specimens, consisting of uranium mononitride (UN) fuel cylinders clad with tungsten-

lined T-111 alloy, were exposed in a pumped lithium loop operated at 1040 °C (1905 °F) for up to 7500 h. The lithium flow velocity was 1.5 m/s (5 ft/s) in the specimen test section. A cladding crack was simulated in one specimen exposed for 50,000 h by an axial slot machined through both the cladding and the tungsten liner.

All of the fuel element specimens appeared to be in excellent condition after the tests. No evidence of any chemical compatibility problems between the specimens and the flowing lithium was found. Except for a slight reduction in the oxygen content of the T-111, very little change in chemistry was observed in the T-111 or the UN. No microstructural changes were observed in the UN, but bands of fine precipitates were seen in the T-111 after the lithium exposure. These precipitates were thought to be the result of thermal aging, not lithium exposure.

Direct exposure of the UN to the lithium through the simulated cladding crack resulted in some erosion of the UN and in some nitrogen contamination of the T-111 cladding in the area of the defect. The T-111 in the fuel element clad specimens was ductile after the long-term lithium exposure. Thermal aging at 1040 °C (1905 °F), however, resulted in the T-111 becoming sensitive to hydrogen embrittlement during post-test handling and testing.

Tantalum is unattacked by molten magnesium at 1150 °C (2100 °F). The limited amount of corrosion testing of refractory metals in mercury is summarized below. The results for tantalum are consistent with the solubility information. In static tests, tantalum exhibited good resistance to mercury at temperatures to 600 °C (1110 °F). Refluxing capsule tests showed no attack of tantalum up to 760 °C (1400 °F). The corrosion resistance of tantalum to mercury was further documented in a two-phase natural-circulation loop test that ran for 19,975 h with a boiling temperature of 650 °C (1200 °F) and superheat temperature of 705 °C (1300 °F).

Post-test evaluation of the loop revealed no corrosion. As a result of the inertness of tantalum to mercury attack demonstrated in this long-term experiment, tantalum was evaluated as a replacement material for Croloy 9M steel in a mercury boiler.

The compatibility of tantalum and potassium at 600, 800, and 1000 °C (1110, 1470, and 1830 °F) was studied in static capsule tests. As the oxygen concentration of potassium was increased, the amount of tantalum in the potassium was also found to increase. The results indicated the formation of an unidentified ternary oxide phase that is either nonadherent or dissolved when the potassium is dissolved for chemical analysis. When the tantalum specimens contained oxygen above a certain threshold concentration, potassium penetrated the tantalum, and intergranular, as well as transgranular, attack was observed. The threshold levels for intergranular attack at the test temperatures were found to be 500, 700, and 1000 ppm oxygen, respectively. The mechanism of attack was believed to be the formation of a ternary oxide phase.

Tantalum is only slightly attacked by silver at 1200 °C (2190 °F); a tantalum crucible tested in silver at this temperature for 35 days showed a loss in wall thickness of 0.02 mm (0.8 mil). Liquid sodium, potassium, or alloys of these elements have little effect on tantalum at temperatures up to 1000 °C (1830 °F), but oxygen contamination of sodium causes increases in corrosion. Sodium does not alloy with tantalum.

The presence of oxygen in liquid sodium leads to slight weight loss of tantalum in flowing systems. In addition, extensive intergranular and transgranular attack of tantalum by sodium was observed. This attack was attributed to the high (390 ppm) oxygen concentration of the tantalum before exposure to the sodium.

The compatibility of tantalum alloys T-111 and Ta-10W with static sodium was demonstrated in capsules tested at 1315 °C (2400 °F) for 6271 and 300 h, respectively. No corrosion was found in either alloy.

Corrosion of candidate construction materials for stills to extract radioactive polonium-210 from bismuth by distillation at temperatures of 450 to 950 °C (840 to 1740 °F) was investigated. Tellurium, which is chemically similar to polonium, was used as a nonradioactive substitute for polonium. Of the materials investigated, tantalum appeared to be the most satisfactory from the standpoint of fabricability and long-term corrosion resistance. Tantalum was corroded at rates up to 0.5 μm/h (0.02 mil/h) during the initial 100 to 200 h of exposure; the rate decreased to less than 0.05 μm/h (0.002 mil/h) after 400 h for concentrations of tellurium of less than 30% in bismuth.

In static tests, the thorium-magnesium eutectic had no appreciable effect on tantalum at 1000 °C (1830 °F). No measurable corrosion of tantalum by the thorium-magnesium eutectic was noted in dynamic tests for 28 days with a temperature range of 700 to 840 °C (1290 to 1545 °F). Extensive tests on components for molten-metal fuel reactors revealed that tantalum is a satisfactory material for several thousand hours of service in high-temperature circulating loops containing a molten magnesium-thorium alloy with a composition in the range of the magnesium-rich eutectic.

Short-term tests indicated that the practical upper limit for tantalum as a container material for uranium is about 1450 °C (2640 °F). However, attack below this temperature is also significant, because a tantalum crucible with a wall thickness of 1.5 mm (0.06 in.) was completely corroded within a test period of 50 h at 1275 °C (2325 °F). Other investigations showed that tantalum is not attacked by uranium-magnesium and plutonium-magnesium alloys at 1150 °C (2100 °F). Extensive tests on components for molten-metal fuel reactors revealed that tantalum is a satisfactory material for several thousand hours of service in several liquid-metal environments.

Tantalum is attacked by zinc, the surface of which is abraded in zinc at 440 °C (825 °F); also, molten zinc attacks tantalum at significant rates at temperatures above 450 °C (840 °F). Tantalum showed appreciable attack from molten zinc at 750 °C (1380 °F). However, one industrial zinc producer observed excellent corrosion resistance at 500 °C (930 °F). The maintenance of the oxide film on the tantalum may account for the latter result.

The intermetallic compounds YSb, ErSb, LaSb, and YBi have little effect on tantalum at 1800 to 2000 °C (3270 to 3630 °F), but antimony vapor severely attacks tantalum at temperatures of 1000 °C (1830 °F) and higher.

Titanium

Several metals, both in liquid and solid form, have been found to induce cracking in contact with titanium alloys. The first reported incidence stemmed from a cracked compressor disk in contact with cadmium-plated steel bolts. Initial speculation hinted that the exposure temperature may have been above the melting point of camium, leading to liquid-metal embrittlement. However, later work found that cracking would occur well below the melting point of cadmium, such as at room temperature for Ti-6Al-4V.

Those metals known to cause cracking of titanium alloys include cadmium, mercury, zinc, and certain silver brazing alloys. The titanium alloys that are known to be susceptible to cracking in cadmium include commercially pure titanium (ASTM grade 3) with more than 0.2% oxygen, Ti-4Al-4Mn, Ti-8Mn, Ti-31V-11Cr-3Al, Ti-6Al-4V, and Ti-8Al-

1Mo-1V. It is likely that most other titanium alloys are susceptible, but have not been tested.

Alloys tested and found to crack in mercury include commercially pure titanium (ASTM grade 4, ~0.3% oxygen), Ti-8Mn, Ti-31V-11Cr-3Al, Ti-6Al-4V, and Ti-8Al-1Mo-1V. As with cadmium, other alloys are probably susceptible, but have not been tested.

Zinc, in both solid and liquid form, has been reported to cause cracking of titanium alloys. However, there is conflicting evidence in the literature as to whether this is actually the case.

Silver and silver brazing alloys have been shown to cause cracking in titanium alloys that are particularly sensitive to stress-corrosion cracking. These alloys include Ti-8Al-1Mo-1V, Ti-5Al-2.5Sn, and Ti-7Al-4Mo. As with cadmium, both solid and liquid forms of silver may produce cracking. Susceptibility for Ti-6Al-4V is considered to be above 345 °C (650 °F).

Titanium exhibits good resistance to many liquid metals at moderately elevated temperatures, where corrosion rates increase with temperature and flow rate. These metals include molten aluminum, sodium, potassium, sodium-potassium mixtures, magnesium, tin, and lead. In contrast, useful performance of titanium in molten lithium, bismuth, zinc, gallium, cadmium, and mercury is limited to relatively low temperatures. Liquid mercury below 150 °C (300 °F) does not appear to affect titanium unless wetting of freshly exposed (mechanically damaged) surfaces occurs. Liquid cadmium, silver, and mercury may cause stress-corrosion cracking of titanium alloys.

Zirconium and Hafnium

Liquid cesium and liquid mercury cause stress-corrosion cracking of zirconium alloys. Hafnium is superior to zirconium and Zircaloy alloys in corrosion resistance in molten alkali metals.

Corrosion Behavior of Various Metals and Alloys in Liquid Metals

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Molten bismuth	...	...	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Molten lead	...	...	...	Resistant	...	92
Irons and alloys									
Gray cast iron	F10001	...	Molten aluminum	...	600 (1110)	...	0.25 (10) min	...	104
Gray cast iron	F10001	...	Molten antimony	...	600 (1110)	...	0.25 (10) min	...	104
Gray cast iron	F10001	...	Molten bismuth-lead-tin	...	300 (570)	...	0.025 (1.0) max	...	104
Gray cast iron	F10001	...	Molten cadmium	...	300 (570)	...	0.025 (1.0) max	...	104
Gray cast iron	F10001	...	Molten cadmium	...	600 (1110)	...	0.025 (1.0) max	...	104
Gray cast iron	F10001	...	Molten lead	...	300 (570)	...	0.025 (1.0) max	...	104
Gray cast iron	F10001	...	Molten magnesium	...	600 (1110)	...	0.025 (1.0) max	...	104
Gray cast iron	F10001	...	Molten tin	...	300 (570)	...	0.25 (10) max	...	104
Gray cast iron	F10001	...	Molten tin	...	600 (1110)	...	0.25 (10) min	...	104
Gray cast iron	F10001	...	Molten zinc	...	600 (1110)	...	0.25 (10) min	...	104
Gray cast iron	F10001	...	Potassium mixtures	...	300 (570)	...	0.25 (10) max	...	104
Nickel and alloys									
Hastelloy alloy X	N06002	...	Molten zinc	...	454 (850)	50 h	0.6 (24.0) min	...	63
Haynes No.625	N06625	...	Molten zinc	...	454 (850)	50 h	0.6 (24.0) min	...	63
Incoloy Alloy 800H	N08810	...	Molten zinc	...	454 (850)	50 h	0.28 (11.0)	...	63
Refractory metals and alloys									
Haynes No.188	R30188	...	Molten zinc	...	454 (850)	50 h	0.06 (2.5)	...	63
Haynes No.188	R30556	...	Molten zinc	...	454 (850)	50 h	0.04 (1.6)	...	63
Haynes No.25	R30605	...	Molten zinc	...	454 (850)	50 h	0.06 (2.3)	...	63
Tantalum	R05210	...	Al-18Th-6U	...	To 1000 (1830)	...	Resistant	...	105
Tantalum	R05210	...	Bi-10U-0.5Mn in helium	...	To 1160 (2120)	...	Resistant	...	105
Tantalum	R05210	...	Bi-5 to 10U, in helium	...	To 1100 (2010)	...	Resistant	...	105
Tantalum	R05210	...	Bi-5U-0.3Mn, in helium	...	To 1050 (1920)	...	Resistant	...	105
Tantalum	R05210	...	ErSb intermetallic compound	...	To 1800-2000 (3270-3630)	...	Resistant	...	105
Tantalum	R05210	...	LaSb intermetallic compound	...	To 1800-2000 (3270-3630)	...	Resistant	...	105
Tantalum	R05210	...	Molten aluminum	...	Molten	...	Poor	...	105
Tantalum	R05210	...	Molten antimony	...	To 1000 (1830)	...	Poor	...	105
Tantalum	R05210	...	Molten bismuth	...	To 900 (1650)	...	Resistant	...	105
Tantalum	R05210	...	Molten cadmium	...	Molten	...	Resistant	...	105
Tantalum	R05210	...	Molten gallium	...	To 450 (840)	...	Resistant	...	105
Tantalum	R05210	...	Molten lead	...	To 1000 (1830)	...	Resistant	...	105

(Continued)

Corrosion Behavior of Various Metals and Alloys in Liquid Metals (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Tantalum	R05210	...	Molten lithium	...	To 1000 (1830)	...	Resistant	...	105
Tantalum	R05210	...	Molten magnesium	...	To 1150 (2100)	...	Resistant	...	105
Tantalum	R05210	...	Molten mercury	...	To 600 (1110)	...	Resistant	...	105
Tantalum	R05210	...	Molten Mg-37Th in helium	...	To 800 (1470)	...	Resistant	...	105
Tantalum	R05210	...	Molten potassium	...	To 900 (1650)	...	Resistant	...	105
Tantalum	R05210	...	Molten sodium	...	To 900 (1650)	...	Resistant	...	105
Tantalum	R05210	...	Molten sodium-potassium alloys	...	To 900 (1650)	...	Resistant	...	105
Tantalum	R05210	...	Molten tin	...	...	...	Questionable	...	105
Tantalum	R05210	...	Molten uranium	...	...	...	Questionable	...	105
Tantalum	R05210	...	Molten YBi intermetallic compound	...	To 1800-2000 (3270-3630)	...	Resistant	...	105
Tantalum	R05210	...	Molten YSb intermetallic compound	...	To 1800-2000 (3270-3630)	...	Resistant	...	105
Tantalum	R05210	...	Molten zinc	...	To 500 (930)	...	Resistant/Questionable	...	105
Tantalum	R05210	...	Plutonium-cobalt-cerium	...	To 650 (1200)	...	Questionable	...	105
Tantalum	R05210	...	U-10Fe	...	To 900 (1650)	...	Resistant	...	105
Tantalum	R05210	...	U-Cr (eutectic)	...	To 900 (1650)	...	Resistant	...	105
Titanium	...	...	Molten aluminum	...	750 (1380)	...	0.1 (4) max	...	103
Titanium	...	...	Molten aluminum	...	850 (1560)*	...	0.1 (4) min	...	103
Titanium	...	...	Molten bismuth-lead	...	300 (570)	...	0.1 (4) max	...	103
Titanium	...	...	Molten bismuth-lead	...	600 (1110)	...	1.3 (50) max	...	103
Titanium	...	...	Molten cadmium	...	500 (930)	...	1.0 (40) min	...	103
Titanium	...	...	Molten gallium	...	400 (750)	...	0.1 (4)	...	103
Titanium	...	...	Molten gallium	...	450 (840)	...	1.0 (40) min	...	103
Titanium	...	...	Molten lead	...	816 (1503)	...	Poor	...	90
Titanium	...	...	Molten lead	...	324-593 (615-1101)	...	Good	...	90
Titanium	...	...	Molten lead	...	400 (750)	...	0.13 (5) max	...	103
Titanium	...	...	Molten lead	...	600-950 (1110-1740)	...	1.0 (40) max	...	103
Titanium	...	...	Molten lithium	...	316-482 (601-900)	...	Resistant	...	90
Titanium	...	...	Molten lithium	...	850 (1560)	...	1.0 (40) max	...	103
Titanium	...	...	Molten magnesium	...	760 (1400)	...	Questionable	...	90
Titanium	...	...	Molten magnesium	...	750 (1380)	...	0.1 (4)	...	103
Titanium	...	...	Molten magnesium	...	850 (1560)	...	1.0 (40) max	...	103
Titanium	...	...	Molten mercury	...	150 (300)	...	0.1 (4) max	...	103
Titanium	...	...	Molten mercury	...	150-300 (300-570)	...	1.0 (40) max	...	103
Titanium	...	...	Molten sodium, potassium	...	600 (1110)	...	0.1 (4) max	...	103
Titanium	...	...	Molten sodium, potassium	...	800 (1470)	...	1.0 (40) max	...	103
Titanium	...	...	Molten tin	...	350 (660)	...	0.1 (4) max	...	103
Titanium	...	...	Molten tin	...	600 (1110)	...	1.0 (40) max	...	103
Titanium	...	...	Molten zinc	...	445 (830)	...	1.0 (40) min	...	103
Stainless steels									
301	S30100	...	Mercury	...	20 (68)	...	Resistant	...	253
301	S30100	...	Mercury	...	50 (122)	...	Resistant	...	253
301	S30100	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
301	S30100	...	Molten antimony	...	650 (1202)	...	Poor	...	253
301	S30100	...	Molten cadmium	...	...	...	Questionable	...	253
301	S30100	...	Molten lead	...	600 (1112)	...	Good	...	253
301	S30100	...	Molten tin	...	200 (392)	...	Resistant	...	253
301	S30100	...	Molten tin	...	400 (752)	...	Good	...	253
301	S30100	...	Molten tin	...	600 (1112)	...	Poor	...	253
301	S30100	...	Molten zinc	...	500 (932)	...	Poor	...	253
302	S30200	...	Mercury	...	20 (68)	...	Resistant	...	253
302	S30200	...	Mercury	...	50 (122)	...	Resistant	...	253
302	S30200	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
302	S30200	...	Molten antimony	...	650 (1202)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Liquid Metals (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	Molten cadmium	...	...	...	Questionable	...	253
302	S30200	...	Molten lead	...	600 (1112)	...	Good	...	253
302	S30200	...	Molten tin	...	200 (392)	...	Resistant	...	253
302	S30200	...	Molten tin	...	400 (752)	...	Good	...	253
302	S30200	...	Molten tin	...	600 (1112)	...	Poor	...	253
302	S30200	...	Molten zinc	...	500 (932)	...	Poor	...	253
303	S30300	...	Mercury	...	20 (68)	...	Resistant	...	253
303	S30300	...	Mercury	...	20 (68)	...	Resistant	...	253
303	S30300	...	Mercury	...	50 (122)	...	Resistant	...	253
303	S30300	...	Mercury	...	50 (122)	...	Resistant	...	253
303	S30300	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
303	S30300	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
303	S30300	...	Molten antimony	...	650 (1202)	...	Poor	...	253
303	S30300	...	Molten antimony	...	650 (1202)	...	Poor	...	253
303	S30300	...	Molten cadmium	...	...	...	Questionable	...	253
303	S30300	...	Molten lead	...	600 (1112)	...	Good	...	253
303	S30300	...	Molten tin	...	200 (392)	...	Questionable	...	253
303	S30300	...	Molten tin	...	200 (392)	...	Resistant	...	253
303	S30300	...	Molten tin	...	400 (752)	...	Poor	...	253
303	S30300	...	Molten tin	...	400 (752)	...	Good	...	253
303	S30300	...	Molten tin	...	600 (1112)	...	Poor	...	253
303	S30300	...	Molten tin	...	600 (1112)	...	Poor	...	253
303	S30300	...	Molten zinc	...	500 (932)	...	Poor	...	253
303	S30300	...	Molten zinc	...	500 (932)	...	Poor	...	253
304	S30400	...	Mercury	...	20 (68)	...	Resistant	...	253
304	S30400	...	Mercury	...	50 (122)	...	Resistant	...	253
304	S30400	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
304	S30400	...	Molten antimony	...	650 (1202)	...	Poor	...	253
304	S30400	...	Molten cadmium	...	...	...	Questionable	...	253
304	S30400	...	Molten lead	...	600 (1112)	...	Good	...	253
304	S30400	...	Molten tin	...	200 (392)	...	Resistant	...	253
304	S30400	...	Molten tin	...	400 (752)	...	Good	...	253
304	S30400	...	Molten tin	...	600 (1112)	...	Poor	...	253
304	S30400	...	Molten zinc	...	454 (850)	50 h	0.35 (14.1)	...	63
304	S30400	...	Molten zinc	...	500 (932)	...	Poor	...	253
304L	S30403	...	Mercury	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Mercury	...	50 (122)	...	Resistant	...	253
304L	S30403	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
304L	S30403	...	Molten antimony	...	650 (1202)	...	Poor	...	253
304L	S30403	...	Molten cadmium	...	...	...	Questionable	...	253
304L	S30403	...	Molten lead	...	600 (1112)	...	Good	...	253
304L	S30403	...	Molten tin	...	200 (392)	...	Resistant	...	253
304L	S30403	...	Molten tin	...	400 (752)	...	Good	...	253
304L	S30403	...	Molten tin	...	600 (1112)	...	Poor	...	253
304L	S30403	...	Molten zinc	...	500 (932)	...	Poor	...	253
304LN	S30453	...	Mercury	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Mercury	...	50 (122)	...	Resistant	...	253
304LN	S30453	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
304LN	S30453	...	Molten antimony	...	650 (1202)	...	Poor	...	253
304LN	S30453	...	Molten cadmium	...	...	...	Questionable	...	253
304LN	S30453	...	Molten lead	...	600 (1112)	...	Good	...	253
304LN	S30453	...	Molten tin	...	200 (392)	...	Resistant	...	253
304LN	S30453	...	Molten tin	...	400 (752)	...	Good	...	253
304LN	S30453	...	Molten tin	...	600 (1112)	...	Poor	...	253
304LN	S30453	...	Molten zinc	...	500 (932)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Liquid Metals (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Mercury	...	20 (68)	...	Resistant	...	253
316	S31600	...	Mercury	...	50 (122)	...	Resistant	...	253
316	S31600	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
316	S31600	...	Molten antimony	...	650 (1202)	...	Poor	...	253
316	S31600	...	Molten cadmium	...	...	...	Questionable	...	253
316	S31600	...	Molten tin	...	200 (392)	...	Resistant	...	253
316	S31600	...	Molten tin	...	400 (752)	...	Good	...	253
316	S31600	...	Molten tin	...	600 (1112)	...	Poor	...	253
316	S31600	...	Molten zinc	...	500 (932)	...	Poor	...	253
316F	S31620	...	Mercury	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Mercury	...	50 (122)	...	Resistant	...	253
316F	S31620	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
316F	S31620	...	Molten antimony	...	650 (1202)	...	Poor	...	253
316F	S31620	...	Molten cadmium	...	...	...	Questionable	...	253
316F	S31620	...	Molten lead	...	600 (1112)	...	Good	...	253
316F	S31620	...	Molten tin	...	200 (392)	...	Resistant	...	253
316F	S31620	...	Molten tin	...	400 (752)	...	Good	...	253
316F	S31620	...	Molten tin	...	600 (1112)	...	Poor	...	253
316F	S31620	...	Molten zinc	...	500 (932)	...	Poor	...	253
316L	S31603	...	Mercury	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Mercury	...	50 (122)	...	Resistant	...	253
316L	S31603	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
316L	S31603	...	Molten antimony	...	650 (1202)	...	Poor	...	253
316L	S31603	...	Molten cadmium	...	...	...	Questionable	...	253
316L	S31603	...	Molten tin	...	200 (392)	...	Resistant	...	253
316L	S31603	...	Molten tin	...	400 (752)	...	Good	...	253
316L	S31603	...	Molten tin	...	600 (1112)	...	Poor	...	253
316L	S31603	...	Molten zinc	...	500 (932)	...	Poor	...	253
316LN	S31653	...	Mercury	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Mercury	...	50 (122)	...	Resistant	...	253
316LN	S31653	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
316LN	S31653	...	Molten antimony	...	650 (1202)	...	Poor	...	253
316LN	S31653	...	Molten cadmium	...	...	...	Questionable	...	253
316LN	S31653	...	Molten tin	...	200 (392)	...	Resistant	...	253
316LN	S31653	...	Molten tin	...	400 (752)	...	Good	...	253
316LN	S31653	...	Molten tin	...	600 (1112)	...	Poor	...	253
316LN	S31653	...	Molten zinc	...	500 (932)	...	Poor	...	253
316Ti	S31635	...	Mercury	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Mercury	...	50 (122)	...	Resistant	...	253
316Ti	S31635	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
316Ti	S31635	...	Molten antimony	...	650 (1202)	...	Poor	...	253
316Ti	S31635	...	Molten cadmium	...	...	...	Questionable	...	253
316Ti	S31635	...	Molten tin	...	200 (392)	...	Resistant	...	253
316Ti	S31635	...	Molten tin	...	400 (752)	...	Good	...	253
316Ti	S31635	...	Molten tin	...	600 (1112)	...	Poor	...	253
316Ti	S31635	...	Molten zinc	...	500 (932)	...	Poor	...	253
317L	S31703	...	Mercury	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Mercury	...	50 (122)	...	Resistant	...	253
317L	S31703	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
317L	S31703	...	Molten antimony	...	650 (1202)	...	Poor	...	253
317L	S31703	...	Molten cadmium	...	...	...	Questionable	...	253
317L	S31703	...	Molten tin	...	200 (392)	...	Resistant	...	253
317L	S31703	...	Molten tin	...	400 (752)	...	Good	...	253
317L	S31703	...	Molten tin	...	600 (1112)	...	Poor	...	253
317L	S31703	...	Molten zinc	...	500 (932)	...	Poor	...	253

(Continued)

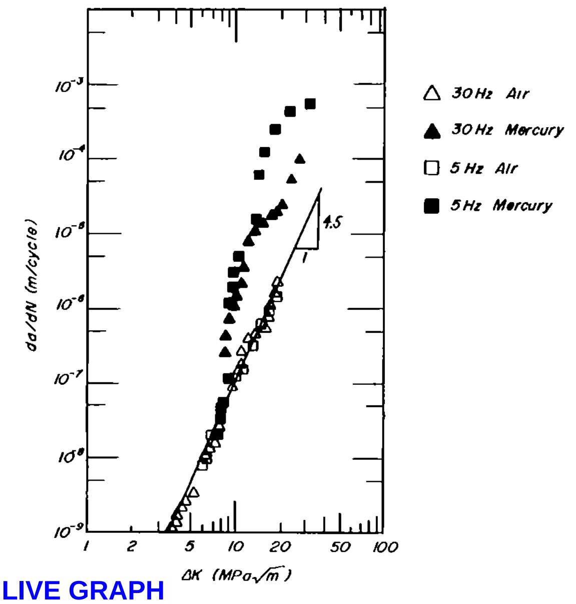
Corrosion Behavior of Various Metals and Alloys in Liquid Metals (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	Mercury	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Mercury	...	50 (122)	...	Resistant	...	253
317LN	S31725	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
317LN	S31725	...	Molten antimony	...	650 (1202)	...	Poor	...	253
317LN	S31725	...	Molten cadmium	...	...	...	Questionable	...	253
317LN	S31725	...	Molten tin	...	200 (392)	...	Resistant	...	253
317LN	S31725	...	Molten tin	...	400 (752)	...	Good	...	253
317LN	S31725	...	Molten tin	...	600 (1112)	...	Poor	...	253
317LN	S31725	...	Molten zinc	...	500 (932)	...	Poor	...	253
321	S32100	...	Mercury	...	20 (68)	...	Resistant	...	253
321	S32100	...	Mercury	...	50 (122)	...	Resistant	...	253
321	S32100	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
321	S32100	...	Molten antimony	...	650 (1202)	...	Poor	...	253
321	S32100	...	Molten cadmium	...	...	...	Questionable	...	253
321	S32100	...	Molten lead	...	600 (1112)	...	Good	...	253
321	S32100	...	Molten tin	...	200 (392)	...	Resistant	...	253
321	S32100	...	Molten tin	...	400 (752)	...	Good	...	253
321	S32100	...	Molten tin	...	600 (1112)	...	Poor	...	253
321	S32100	...	Molten zinc	...	500 (932)	...	Poor	...	253
329	S32900	...	Mercury	...	20 (68)	...	Resistant	...	253
329	S32900	...	Mercury	...	50 (122)	...	Resistant	...	253
329	S32900	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
329	S32900	...	Molten antimony	...	650 (1202)	...	Poor	...	253
329	S32900	...	Molten cadmium	...	...	...	Questionable	...	253
329	S32900	...	Molten tin	...	200 (392)	...	Resistant	...	253
329	S32900	...	Molten tin	...	400 (752)	...	Good	...	253
329	S32900	...	Molten tin	...	600 (1112)	...	Poor	...	253
329	S32900	...	Molten zinc	...	500 (932)	...	Poor	...	253
347	S34700	...	Mercury	...	20 (68)	...	Resistant	...	253
347	S34700	...	Mercury	...	50 (122)	...	Resistant	...	253
347	S34700	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
347	S34700	...	Molten antimony	...	650 (1202)	...	Poor	...	253
347	S34700	...	Molten cadmium	...	...	...	Questionable	...	253
347	S34700	...	Molten lead	...	600 (1112)	...	Good	...	253
347	S34700	...	Molten tin	...	200 (392)	...	Resistant	...	253
347	S34700	...	Molten tin	...	400 (752)	...	Good	...	253
347	S34700	...	Molten tin	...	600 (1112)	...	Poor	...	253
347	S34700	...	Molten zinc	...	500 (932)	...	Poor	...	253
403	S40300	...	Mercury	...	20 (68)	...	Resistant	...	253
403	S40300	...	Mercury	...	50 (122)	...	Resistant	...	253
403	S40300	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
403	S40300	...	Molten antimony	...	650 (1202)	...	Poor	...	253
403	S40300	...	Molten tin	...	200 (392)	...	Questionable	...	253
403	S40300	...	Molten tin	...	400 (752)	...	Poor	...	253
403	S40300	...	Molten tin	...	600 (1112)	...	Poor	...	253
403	S40300	...	Molten zinc	...	500 (932)	...	Poor	...	253
405	S40500	...	Mercury	...	20 (68)	...	Resistant	...	253
405	S40500	...	Mercury	...	50 (122)	...	Resistant	...	253
405	S40500	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
405	S40500	...	Molten antimony	...	650 (1202)	...	Poor	...	253
405	S40500	...	Molten tin	...	200 (392)	...	Questionable	...	253
405	S40500	...	Molten tin	...	400 (752)	...	Poor	...	253
405	S40500	...	Molten tin	...	600 (1112)	...	Poor	...	253
405	S40500	...	Molten zinc	...	500 (932)	...	Poor	...	253
409	S40900	...	Mercury	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Liquid Metals (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	Mercury	...	50 (122)	...	Resistant	...	253
409	S40900	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
409	S40900	...	Molten antimony	...	650 (1202)	...	Poor	...	253
409	S40900	...	Molten tin	...	200 (392)	...	Questionable	...	253
409	S40900	...	Molten tin	...	400 (752)	...	Poor	...	253
409	S40900	...	Molten tin	...	600 (1112)	...	Poor	...	253
409	S40900	...	Molten zinc	...	500 (932)	...	Poor	...	253
410	S41000	...	Mercury	...	20 (68)	...	Resistant	...	253
410	S41000	...	Mercury	...	50 (122)	...	Resistant	...	253
410	S41000	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
410	S41000	...	Molten antimony	...	650 (1202)	...	Poor	...	253
410	S41000	...	Molten tin	...	200 (392)	...	Questionable	...	253
410	S41000	...	Molten tin	...	400 (752)	...	Poor	...	253
410	S41000	...	Molten tin	...	600 (1112)	...	Poor	...	253
410	S41000	...	Molten zinc	...	500 (932)	...	Poor	...	253
416	S41600	...	Mercury	...	20 (68)	...	Resistant	...	253
416	S41600	...	Mercury	...	50 (122)	...	Resistant	...	253
416	S41600	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
416	S41600	...	Molten antimony	...	650 (1202)	...	Poor	...	253
416	S41600	...	Molten tin	...	200 (392)	...	Questionable	...	253
416	S41600	...	Molten tin	...	400 (752)	...	Poor	...	253
416	S41600	...	Molten tin	...	600 (1112)	...	Poor	...	253
416	S41600	...	Molten zinc	...	500 (932)	...	Poor	...	253
420	S42000	...	Mercury	...	20 (68)	...	Resistant	...	253
420	S42000	...	Mercury	...	50 (122)	...	Resistant	...	253
420	S42000	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
420	S42000	...	Molten antimony	...	650 (1202)	...	Poor	...	253
420	S42000	...	Molten tin	...	200 (392)	...	Questionable	...	253
420	S42000	...	Molten tin	...	400 (752)	...	Poor	...	253
420	S42000	...	Molten tin	...	600 (1112)	...	Poor	...	253
420	S42000	...	Molten zinc	...	500 (932)	...	Poor	...	253
430	S43000	...	Mercury	...	20 (68)	...	Resistant	...	253
430	S43000	...	Mercury	...	50 (122)	...	Resistant	...	253
430	S43000	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
430	S43000	...	Molten antimony	...	650 (1202)	...	Poor	...	253
430	S43000	...	Molten tin	...	200 (392)	...	Questionable	...	253
430	S43000	...	Molten tin	...	400 (752)	...	Poor	...	253
430	S43000	...	Molten tin	...	600 (1112)	...	Poor	...	253
430	S43000	...	Molten zinc	...	500 (932)	...	Poor	...	253
434	S43400	...	Mercury	...	20 (68)	...	Resistant	...	253
434	S43400	...	Mercury	...	50 (122)	...	Resistant	...	253
434	S43400	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
434	S43400	...	Molten antimony	...	650 (1202)	...	Poor	...	253
434	S43400	...	Molten tin	...	200 (392)	...	Resistant	...	253
434	S43400	...	Molten tin	...	400 (752)	...	Good	...	253
434	S43400	...	Molten tin	...	600 (1112)	...	Poor	...	253
434	S43400	...	Molten zinc	...	500 (932)	...	Poor	...	253
446	S44600	...	Molten zinc	...	454 (850)	50 h	0.23 (9.3)	...	63
F51	S31803	...	Mercury	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Mercury	...	50 (122)	...	Resistant	...	253
F51	S31803	...	Molten aluminum	...	750 (1380)	...	Poor	...	253
F51	S31803	...	Molten antimony	...	650 (1202)	...	Poor	...	253
F51	S31803	...	Molten cadmium	...	...	...	Questionable	...	253
F51	S31803	...	Molten tin	...	200 (392)	...	Resistant	...	253
F51	S31803	...	Molten tin	...	400 (752)	...	Good	...	253
F51	S31803	...	Molten tin	...	600 (1112)	...	Poor	...	253
F51	S31803	...	Molten zinc	...	500 (932)	...	Poor	...	253



LIVE GRAPH
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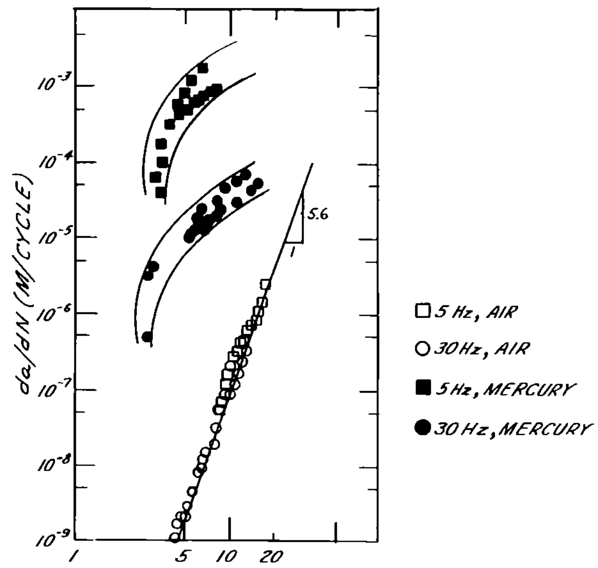
Aluminum. Fatigue loading results for 6061-T651 aluminum alloy exposed to mercury. Open triangle: 30 Hz, air. Closed triangle: 30 Hz, mercury. Open square: 5 Hz, air. Closed square: 5 Hz, mercury. Source: J.A. Kapp, D. Duquette, *et al.*, "Crack Growth Behavior of Aluminum Alloys Tested in Liquid Mercury," *Journal of Engineering Materials and Technology*, Vol 108, Jan 1986, 38.



LIVE GRAPH
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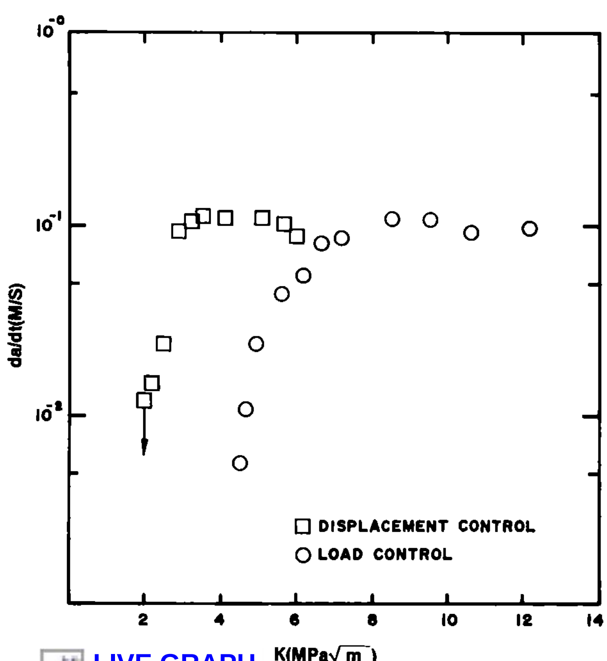
Aluminum. Fatigue loading results for 7075-T651 aluminum alloy exposed to mercury. Open square: 5 Hz, air. Open circle: 30 Hz, air. Closed square: 5 Hz, mercury. Closed circle: 30 Hz, mercury. Source: J.A. Kapp, D. Duquette, *et al.*, "Crack Growth Behavior of Aluminum Alloys Tested in Liquid Mercury," *Journal of Engineering Materials and Technology*, Vol 108, Jan 1986, 38.



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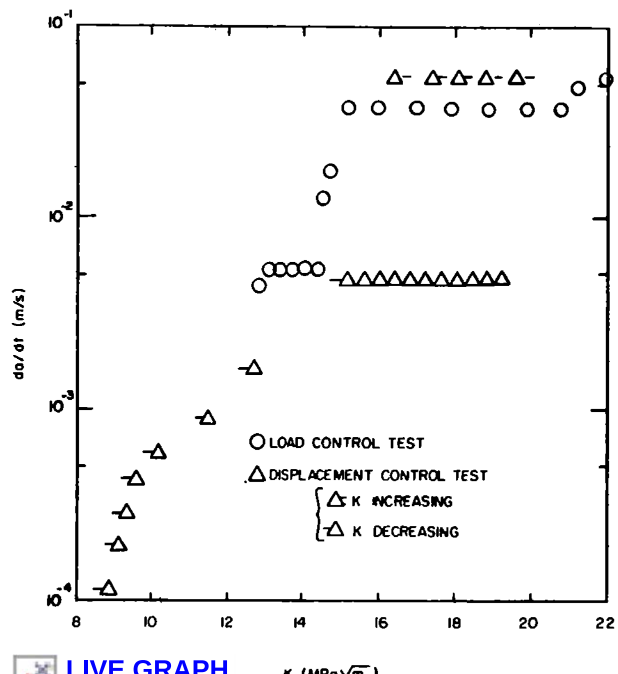
Aluminum. Static loading results for 7075-T651 aluminum alloy exposed to mercury. Source: J.A. Kapp, D. Duquette, *et al.*, "Crack Growth Behavior of Aluminum Alloys Tested in Liquid Mercury," *Journal of Engineering Materials and Technology*, Vol 108, Jan 1986, 40.



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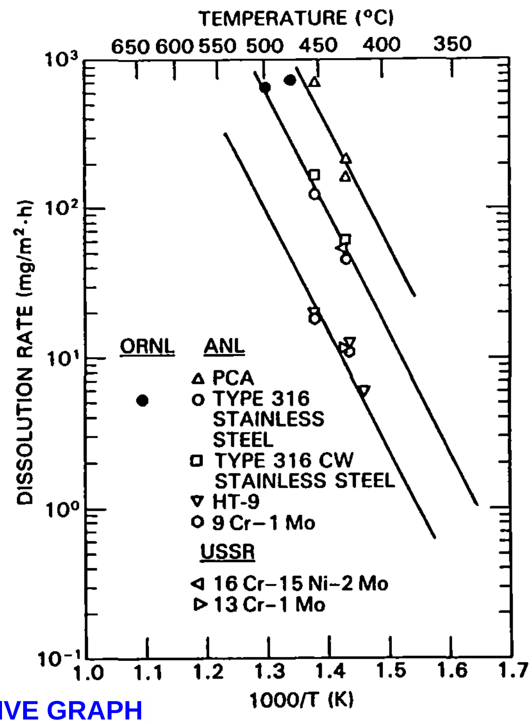
Aluminum. Static loading results for 6061-T651 aluminum alloy exposed to mercury. Source: J.A. Kapp, D. Duquette, *et al.*, "Crack Growth Behavior of Aluminum Alloys Tested in Liquid Mercury," *Journal of Engineering Materials and Technology*, Vol 108, Jan 1986, 39.



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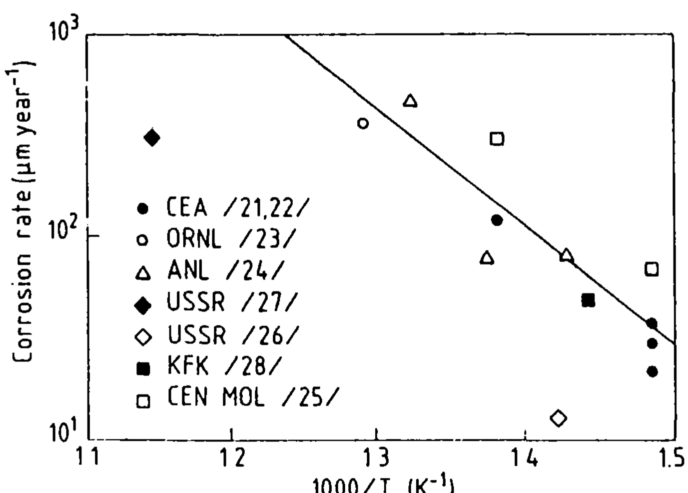
Stainless steel. Arrhenius plot of corrosion rate data for austenitic type 316 stainless steel and ferritic HT-9 alloy and Fe-9Cr-1Mo steel in flowing Pb-17Li. Data are normalized for V = 1.5 m/s. Source: O.K. Chopra, D.L. Smith, *et al.*, "Liquid-Metal Corrosion," *Fusion Technology*, Vol 8, Sept 1985, 1962.



LIVE GRAPH
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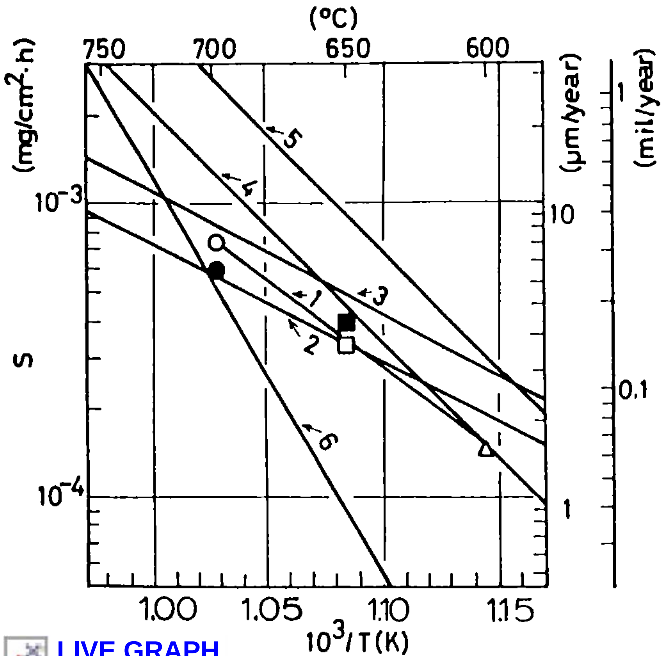
Key:
CEA = Commissariat a l'Energie Atmoique, France
ORNL = Oak Ridge National Lab
ANL = Argonne National Lab
USSR = Russia
KFK = Kernforschungszentrum, Karlsruhe, Germany
CEN = Mol, Belgium

Stainless steel. Influence of temperature on corrosion of 316L steel in flowing Pb-17Li. Ref. 265



Key:
1. 1-2 ppm 0 = Ref. 267 = O, ●, □, ■, ◆
2. 1 ppm 0 = Thorley
3. 2 ppm 0 = Thorley
4. 1 ppm 0 = Bagnall, Jacobs
5. 2 ppm 0 = Bagnall, Jacobs
6. 3.4 ppm 0 = Weeks, Isaacs

LIVE GRAPH
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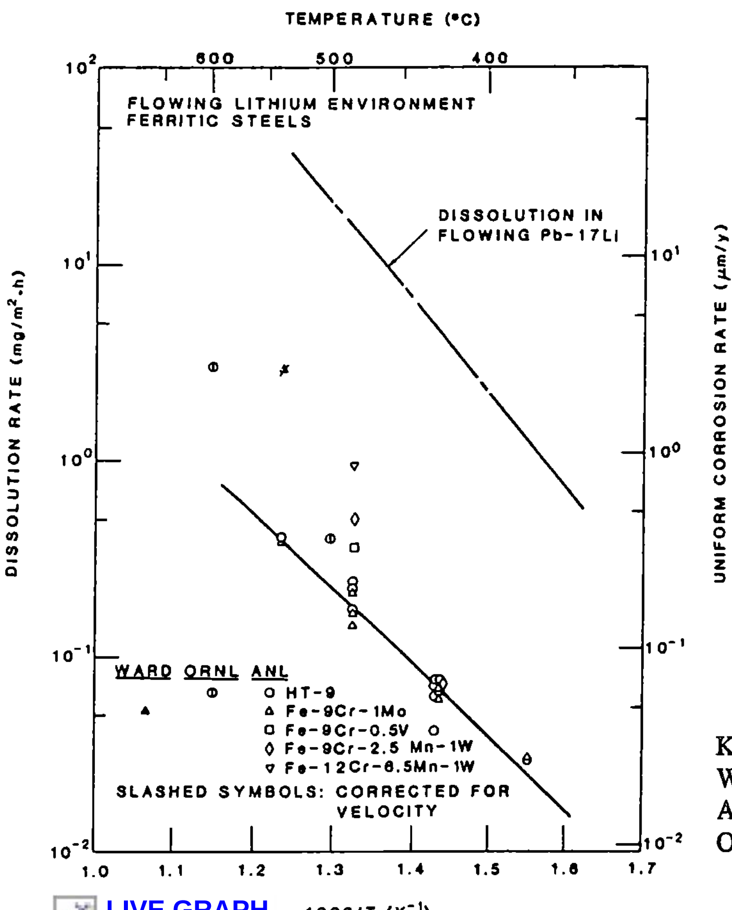
Stainless steel. Relationships between corrosion rate, S, and reciprocal of exposure temperature, $10^3/T$(K), of 316 stainless steel. Ref. 267



Key:
Ward = Westinghouse Advanced Reactor Division
ANL = Argonne National Lab
ORNL = Oak Ridge National Lab

LIVE GRAPH
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Ferritic steels. Arrhenius plots of dissolution rate data for ferritic steels exposed to flowing lithium and Pb-17Li. Ref. 268

Lithium Bromide

Lithium bromide (LiBr) is a white deliquescent, granular powder with a bitter taste, melting at 547 °C; soluble in alcohol and glycol; used to add moisture to air-conditioning systems and as a sedative and hypnotic in medicine. LiBr solution has been established as a practical absorbent for use in absorption refrigeration systems. As most units of a system are primarily made of carbon steel. The LiBr solution circulates in the system varying its concentration and temperature to respective lower values. The LiBr solution is a prominent absorbent in an absorption heat pump system, which has been developed in recent years. Because the operating condition of the pump is different from system to system, wide varieties of concentration and temperature ranges can be expected.

Corrosion Behavior of Various Metals and Alloys in Lithium Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
1040 steel	G10400	...	...	23 m	120	400 h	0.05 (1.9)	...	199
1040 steel	G10400	...	...	2 m	120	400 h	.03 (1.2)	...	199
1040 steel	G10400	...	...	2 m	160	400 h	.03 (1.0)	...	199
1040 steel	G10400	...	...	10 m	100	400 h	.28 (11)	...	199
1040 steel	G10400	...	...	10 m	120	400 h	.09 (3.5)	...	199
1040 steel	G10400	...	...	10 m	160	400 h	.07 (2.7)	...	199
1040 steel	G10400	...	...	23 m	120	400 h	.05 (1.9)	...	199
1040 steel	G10400	...	...	23 m	160	400 h	.11 (4.5)	...	199

Lithium Chloride

Lithium chloride, LiCl, is a white deliquescent solid with a melting point of 614 °C (1140 °F). It is soluble in water and alcohol and dehumidifies air for industrial drying and for air conditioning. Lithium chloride burns with a chrimson flame and is used in pyrotechnics. It is also used as a pyrotechnic in welding and brazing fluxes.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Under laboratory conditions of 100 % relative humidity and ambient temperature, aluminum alloys 3003, 5154, and 6061 were found to be resistant to solid lithium chloride. When the temperature was increased to 54 °C (130 °F), mild attack occurred. Tested in aqueous solutions of 1 to 40%, aluminum alloys 3003, 5052, and 6061 showed local pitting and mild attack (0.075 mm/yr, or 3 mils/yr) at both ambient temperature and 50 °C (122 °F).

Corrosion Behavior of Various Metals and Alloys in Lithium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	...	24 (75)	...	1.3 (50) min	...	95
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lithium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
600	N06600	...	pH 2	8.5	80-95 (176-203)	305 h	.84 (33.1)	...	241
Alloy B-2	N10665	...	pH 0	8.5	80-95 (176-203)	216 h	0.38 (15)	...	241
Alloy C-22	N06022	...	pH 0	8.5	80-95 (176-203)	216 h	1.0 (39)	...	241
Alloy C-22	N06022	...	pH 0	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 0	8.5	65	24 h	0.69 (27)	...	241
Alloy C-22	N06022	...	pH 0	8.5	80	24 h	1.98 (78)	...	241
Alloy C-22	N06022	...	pH 0	8.5	95	24 h	4.32 (170)	...	241
Alloy C-22	N06022	...	pH 0.5	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 0.5	8.5	65	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 0.5	8.5	80	24 h	0.01 (0.4)	...	241
Alloy C-22	N06022	...	pH 0.5	8.5	95	24 h	1.75 (69)	...	241
Alloy C-22	N06022	...	pH 1	8.5	50 (122)	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 1	8.5	65 (149)	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 1	8.5	80 (176)	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 1	8.5	95 (203)	24 h	0.01 (0.4)	...	241
Alloy C-22	N06022	...	pH 2	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 2	8.5	65	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 2	8.5	80	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 2	8.5	95	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 9	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 9	8.5	65	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 9	8.5	80	24 h	.003 (0.1) max	...	241
Alloy C-22	N06022	...	pH 9	8.5	95	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 0	8.5	80-95 (176-203)	216 h	0.91 (36)	...	241
Alloy C-276	N10276	...	pH 0	8.5	80	24 h	0.99	...	241
Alloy C-276	N10276	...	pH 0	8.5	95	24 h	1.68	...	241
Alloy C-276	N10276	...	pH 0.5	8.5	50	24 h	.003 max	...	241
Alloy C-276	N10276	...	pH 0.5	8.5	65	24 h	0.02	...	241
Alloy C-276	N10276	...	pH 0.5	8.5	80	24 h	0.42	...	241
Alloy C-276	N10276	...	pH 0.5	8.5	95	24 h	0.86	...	241
Alloy C-276	N10276	...	pH 1	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 1	8.5	65	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 1	8.5	80	24 h	0.01 (0.4)	...	241
Alloy C-276	N10276	...	pH 1	8.5	95	24 h	0.03 (1.2)	...	241
Alloy C-276	N10276	...	pH 2	8.5	50	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 2	8.5	65	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 2	8.5	80	24 h	.003 (0.1) max	...	241
Alloy C-276	N10276	...	pH 2	8.5	95	24 h	.003 (0.1) max	...	241
Alloy G-30	N06030	...	pH 0	8.5	80-95 (176-203)	216 h	5.2 (205)	...	241
B-2	N10665	...	pH 2	8.5	80-95 (176-203)	305 h	.19 (7.5)	...	241
C-22	N06022	...	pH 2	8.5	80-95 (176-203)	305 h	.003 (0.1)	...	241
C-276	N10276	...	pH 2	8.5	80-95 (176-203)	305 h	.008 (0.3)	...	241
G-30	N06030	...	pH 2	8.5	80-95 (176-203)	305 h	.003 (0.1) max	...	241
Refractory metals and alloys									
Titanium	...	...	...	50	149 (301)	...	Resistant	...	90
Stainless steels									
20Mo-6	N08026	...	pH 0	8.5	80-95 (176-203)	216 h	2.5 (99)	...	241
20Mo-6	N08026	...	pH 2	8.5	80-95 (176-203)	305 h	.003 (0.1)	...	241
304	S30400	...	Air conditioning (evaporator); field or pilot plant test; no aeration; rapid agitation. With carbon over the standard maximum	30	116 (240)	40 d	0.003 (0.1) max	Stress-corrosion cracking	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lithium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Air conditioning (evaporator); field or pilot plant test; no aeration; slight to moderate agitation. Plus vapors from a boiling 30% lithium-chloride solution	...	116 (240)	40 d	Poor	Stress-corrosion cracking	89
304	S30400	...	Chemical (dehydration) processing; field or pilot plant test; no aeration; slight to moderate agitation. With carbon over the standard maximum. Concentration: 30% during 26 days, 25% calcium chloride during 146 days, vacuum	30	-7 to 20 (20-68)	172 d	0.003 (0.1) max	...	89
316	S31600	...	Air conditioning (evaporator); field or pilot plant test; no aeration; rapid agitation	30	116 (240)	40 d	0.003 (0.1) max	Stress-corrosion cracking	89
316	S31600	...	Air conditioning (evaporator); field or pilot plant test; no aeration; slight to moderate agitation. Plus vapors from a boiling 30% lithium-chloride solution	...	116 (240)	40 d	0.17 (6.9)	Severe pitting, stress-corrosion cracking	89
316	S31600	...	Chemical (dehydration) processing; field or pilot plant test; no aeration; slight to moderate agitation. Concentration: 30% during 26 days, 25% calcium chloride during 146 days, vacuum	30	-7 to 20 (20-68)	172 d	0.003 (0.1) max	...	89
Alloy 600	N06600	...	pH 0	8.5	80-95 (176-203)	216 h	5.1 (201)	...	241

Lithium Hydride

Lithium hydride (LiH) is a crystalline salt substance (face-centered cubic) that is white in its pure form. As an engineering material, it has properties of interest in many technologies. For example, the high hydrogen content and light weight of LiH make it useful for neutron shields and moderators in nuclear power plants. In addition, the high heat of fusion combined with light weight make LiH appropriate for heat storage media for solar power plants on satellites and may be used as a heat sink for different applications.

Typically, processes for production of LiH involve handling of LiH at temperatures above its melting point (688 °C). Type 304L stainless steel is utilized for many process components handling molten LiH.

Corrosion Behavior of Various Metals and Alloys in Lithium Hydride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Nickel 200	N02200	...	...	5	...	...	.0011	...	233
Nickel 200	N02200	...	...	8	...	...	.0013	...	233
Stainless steels									
304L	S30403	...	Molten lithium hydrogen	100	715	400 h	.02 (0.9)	...	240
304L	S30403	...	Molten lithium hydrogen	100	760	450 h	.03 (1.4)	...	240
304L	S30403	...	Molten lithium hydrogen	100	800	450 h	.06 (2.3)	...	240
304L	S30403	...	Molten lithium hydrogen	100	850	400 h	.08 (3.4)	...	240

Lithium Hydroxide

Lithium hydroxide (LiOH) forms colorless crystals that are water soluble. An aqueous solution of a lithium salt below its boiling point has been considered for both a tritium breeding blanket and as a coolant in several fusion reactor designs. In order to breed sufficient tritium to fuel the reactor, a high concentration of lithium is desirable and lithium hydroxide is sufficiently soluble for this purpose. The solution would be contained in pipes and heat exchangers, most probably made from carbon steel.

In fact, a good deal of information about the corrosion behavior of carbon steel in solutions of hot, strong alkalis, particularly in sodium hydroxide suggest carbon steel might be suitable. However, much improved corrosion resistance is provided by nickel, nickel base alloys and stainless steels.

Corrosion Behavior of Various Metals and Alloys in Lithium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Carbon steel	G10100	...	...	5	95	...	.43 (17.2)	...	232
Carbon steel	G10100	...	...	8	95	...	.54 (21.6)	...	232
Stainless steels									
26Cr-1Mo	S44627	...	...	5	95	136 d	.0018	...	233
26Cr-1Mo	S44627	...	...	8	95	136 d	.0016	...	233
316L	S31603	...	...	5	95	136 d	.0024	...	233
316L	S31603	...	...	8	95	136 d	.0035	...	233
316L	S31603	...	...	5	95	136 d	.0026	...	233
316L	S31603	...	...	8	95	136 d	.0034	...	233

Lubricating Oil

This oil is a selected fraction of refined mineral oil used for lubrication of moving surfaces, usually metallic, and ranging from small precision machinery such as watches, to the heaviest equipment. Lubricating oils usually have small amounts of additives to impart special properties such as viscosity index and detergency and range in consistency from thin liquids to grease-like substances. In contrast to lubricating greases, lube oils do not contain solid or fibrous materials.

Corrosion Behavior of Various Metals and Alloys in Lubricating Oil

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Lubricating Oil (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Magnesium Bromide

Magnesium bromide, $MgBr_2 \cdot 6H_2O$. is deliquescent, colorless, bitter-tasting crystals, melting at 172 °C; soluble in water, slightly soluble in alcohol and is used in medicine and in the synthesis of organic chemicals.

Corrosion Behavior of Various Metals and Alloys in Lubricating Oil (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Magnesium Bromide

Magnesium bromide, $MgBr_2 \cdot 6H_2O$. is deliquescent, colorless, bitter-tasting crystals, melting at 172 °C; soluble in water, slightly soluble in alcohol and is used in medicine and in the synthesis of organic chemicals.

Corrosion Behavior of Various Metals and Alloys in Magnesium Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
AP65	...	...	1M solution	18	22 (72)	5 h	432 (17290)	...	246
AP65	...	...	2M solution	39	22 (72)	5 h	322 (12910)	...	246
AZ31B	...	...	1M solution	18	22 (72)	5 h	285 (11395)	...	246
AZ31B	...	...	2M solution	39	22 (72)	5 h	233 (9330)	...	246
AZ61A	M11601	...	1M solution	18	22 (72)	5 h	305 (12210)	...	246
AZ61A	M11601	...	2M solution	39	22 (72)	5 h	254 (10140)	...	246
Magnesium	...	...	1M solution	18	22 (72)	5 h	575 (23085)	...	246
Magnesium	...	...	2M solution	39	22 (72)	5 h	449 (17970)	...	246

Magnesium Carbonate

Magnesium carbonate, $MgCO_3$, is a light, bulky white powder, very slightly soluble in water, loses CO_2 even on gentle heating. It is used extensively in the manufacture of food products, pharmaceuticals, cosmetics, and magnesium salts.

Corrosion Behavior of Various Metals and Alloys in Magnesium Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Magnesium Chloride

Magnesium chloride, $MgCl_2$, also known as chloromagnesite, is a colorless crystalline solid with a melting point of 712 °C (1312 °F). It is soluble in water and alcohol and is used in the ceramic and textile industries. Magnesium chloride is formed by heating hydrated magnesium chloride crystals in a current of dry hydrogen chloride or by heating magnesium ammonium chloride. Hydrated magnesium chloride, $MgCl_2{\cdot}6H_2O$, also known as bischophite, is a white deliquescent solid formed by the reaction of magnesium carbonate (or hydroxide, oxide or metal) and hydrogen chloride. It is used in disinfectants, fire extinguishers, and paper manufacture.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Tested under laboratory conditions of ambient temperature and 100% relative humidity, aluminum alloy 3003 resisted solid magnesium chloride. In other tests at ambient temperature, aqueous solutions of magnesium chloride with concentrations up to 10% produced localizing pitting, but overall aluminum alloy 1001 showed good resistance.

Amorphous Metals. The stress-corrosion cracking behavior of a glassy $Fe_{32}Ni_{36}Cr_{14}P_{12}B_6$ alloy in boiling magnesium chloride (125 °C, or 225 °F) was studied by means of constant extension rate tensile tests and constant strain tests. Stress-corrosion cracking observed at the corrosion potential and anodic overpotentials could be prevented with a slight cathodic polarization. After studying the fracture surface, the conclusion was reached that the surface corrosion allowed hydrogen entry and therefore subsequent embrittlement.

Stainless Steels. The austenitic, ferritic and martensitic stainless steels display wide variability in their resistance to pitting and stress-corrosion cracking in magnesium chloride. A more detailed investigation should be performed if stainless steels are to used in the presence of magnesium chloride, especially at elevated temperatures.

Zirconium. Zirconium resists stress-corrosion cracking in magnesium chloride.

TiN and TiC coatings. Average cumulative weight loss of TiN and TiC coatings immersed in boiling magnesium chloride solution. I, TiN coatings; II, TiC coatings; BT, with bond coat and top sealant; no symbols, no bond coat, and no top sealant.

Corrosion Behavior of Various Metals and Alloys in Magnesium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Magnesium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
AP65	...	...	1M solution	10	22 (72)	5 h	830 (33190)	...	246
AP65	...	...	2M solution	19	22 (72)	5 h	...	...	246
AZ31B	...	...	1M solution	10	22 (72)	5 h	575 (23090)	...	246
AZ31B	...	...	2M solution	19	22 (72)	5 h	...	...	246
AZ61A	M11601	...	1M solution	10	22 (72)	5 h	620 (24870)	...	246
AZ61A	M11601	...	2M solution	19	22 (72)	5 h	...	...	246
Lead	L50045	...	...	10-100	24 (75)	...	1.3 (50) min	...	95
Magnesium	...	...	...	All	Room	...	Poor	...	119
Magnesium	...	...	1M solution	10	22 (72)	5 h	945 (37880)	...	246
Magnesium	...	...	2M solution	19	22 (72)	5 h	...	...	246
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	120 (250)	...	0.05 (2) max	...	9
Silver	P07010	...	Melt	...	710 (1310)	...	Poor	...	9
Nickel and alloys									
Nickel 200	N02200	...	...	To 50	Boiling	...	0.075 (3)	...	44
Refractory metals and alloys									
Niobium	R04210	...	...	47	Boiling	...	0.025 (1.0)	...	2
Titanium	...	...	...	5-20	100 (212)	...	0.010 (0.4) max	...	90
Titanium	...	...	...	5-40	Boiling	...	0.005 (0.2)	...	90
Titanium, grade 12	R53400	...	Tight crevices pH 4.2	10	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 4.2	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 4.2	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 4.2	10	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	...	Saturated	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	Tight crevices pH 4.2	10	Boiling	...	Resistant	...	215
Zr702	R60702	...	...	5-40	Room to 100 (Room to 212)	...	0.05 (2) max	...	15
Zr702	R60702	...	...	47	Boiling	...	Resistant	...	15
Zr705	R60705	...	...	47	Boiling	...	Resistant	...	15
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	30	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	10	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	30	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	10	20 (68)	...	Good	Pitting	253
303	S30300	...	...	10	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	30	20 (68)	...	Good	Pitting	253
303	S30300	...	...	30	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	10	21 (70)	...	Questionable	...	121
304	S30400	...	...	10	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	30	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Chemical (evaporation) processing; field or pilot plant test; no aeration; rapid agitation. Boil-down kettle	48	166 (330)	55 d	0.11 (4.3)	...	89
304	S30400	...	Chemical processing; lab test; strong aeration; no agitation. Evaporator	42	156 (312)	35 d	0.003 (0.1)	Severe pitting; stress-corrosion cracking	89

(Continued)

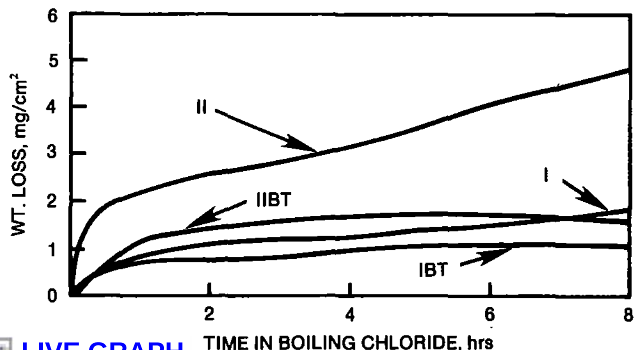
Corrosion Behavior of Various Metals and Alloys in Magnesium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Metal processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.8% sodium chloride, 0.4% calcium chloride, traces of iron, copper, nickel, manganese and sulfates, pH 5-6 (heating coil)	35-36	71 (160)	31 d	0.005 (0.2)	Slight pitting;crevice attack	89
304L	S30403	...	...	10	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	30	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	30	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	10	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	30	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Chemical (evaporation) processing; field or pilot plant test; no aeration; rapid agitation. Boil-down kettle	48	166 (330)	55 d	0.08 (3.2)	Stress-corrosion cracking	89
316	S31600	...	Metal processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 0.8% sodium chloride, 0.4% calcium chloride, traces of iron, copper, nickel, manganese and sulfates, pH 5-6 (heating coil)	35-36	71 (160)	31 d	0.005 (0.2)	Slight pitting; crevice attack	89
316F	S31620	...	...	10	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	30	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	10	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	30	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	30	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	30	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	10	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	30	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	30	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	10	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	30	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	10	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	30	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	10	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	30	20 (68)	...	Resistant	Pitting	253
403	S40300	...	...	10	20 (68)	...	Questionable	Pitting	253
403	S40300	...	...	30	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	10	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	30	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	10	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	30	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	10	21 (70)	...	Questionable	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	10	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	30	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	10	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	30	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	10	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	30	20 (68)	...	Questionable	Pitting	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	20 (68)	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Magnesium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	30	20 (68)	...	Good	Pitting	253
434	S43400	...	...	10	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	30	20 (68)	...	Resistant	Pitting	253
AM-363	S36300	...	...	...	Room	...	Poor	...	120
F51	S31803	...	...	10	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	30	20 (68)	...	Resistant	Pitting	253



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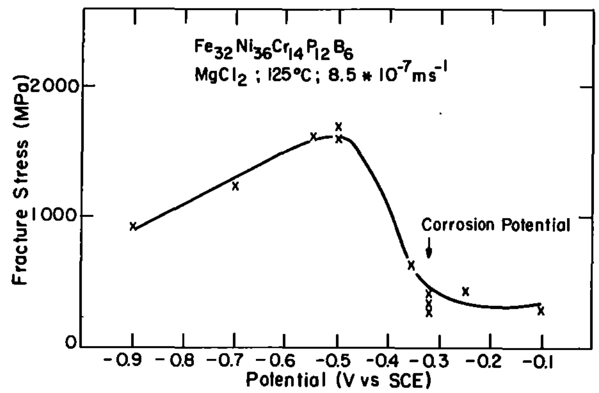
TiN and TiC coatings. Average cumulative weight loss of TiN and TiC coatings immersed in boiling magnesium chloride solution. I, TiN coatings; II, TiC coatings; BT, with bond coat and top sealant; no symbols, no bond coat, and no top sealant.



Metallic Glass. Tensile properties of a glassy $Fe_{32}Ni_{36}Cr_{14}P_{12}B_6$ alloy in constant extension rate tensile tests at a rate of 8.5×10^{-7} ms^{-1} in boiling magnesium chloride at 125 °C as a function of electrochemical potential. Source: R.F. Sandenbergh and R.M. Latanision, "The Stress Corrosion Cracking of a Glassy $Fe_{32}Ni_{36}Cr_{14}P_{12}B_6$ Alloy," *Corrosion,* Vol 41, July 1985, 371.

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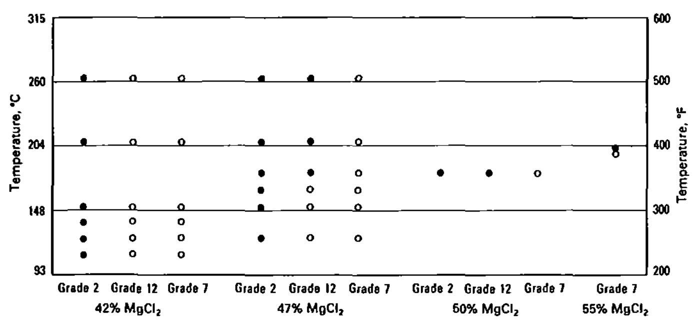


Titanium. Temperature guidelines for avoiding localized attack of grades 2, 7, and 12 titanium in concentrated magnesium chloride solutions in the absence of crevices. Closed circles denote susceptibility to attack. Source: R.W. Schutz and J.S. Grauman, "Selection of Titanium Alloys for Concentrated Seawater, NaCl and $MgCl_2$ Brines," in *Titanium 1986—Titanium Products and Applications,* proceedings of the Technical Program from the 1986 International Conference, San Francisco, Titanium Development Association, 1986.

Magnesium Hydroxide

Magnesium hydroxide, $Mg(OH)_2$, also known as magnesium hydrate and brucite, is a white powder that is very slightly soluble in water. It decomposes at 350 °C (662 °F). It is used in the extraction of magnesium metal and as a reagent in the sulfite wood pulp process. Magnesium hydroxide is formed by the reaction of sodium hydroxide and a soluble magnesium salt solution. Brucite, a mineral composed of magnesium

hydroxide with occasional traces of iron and manganese, is a white to grayish translucent secondary mineral found with serpentine and metamorphic dolomites.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys are generally considered poor choices for caustic service. In laboratory tests, the corrosion rate of aluminum alloy 1100 increased with the increasing pH of the magnesium hydroxide solution. In the construction industry, the contact of magnesium hydroxide-containing building materials with bare aluminum initially causes mild surface corrosion, which leaves a protective film that resists further attack.

Titanium. Titanium alloys generally resist all temperatures and concentrations of magnesium hydroxide. Hydrogen embrittlement may occur in alpha alloys when the temperature exceeds 80 °C (175 °F) and the pH is over 12. The addition of dissolved oxidizing species such as chlorate, hypochlorate, or nitrate compounds may extend resistance to higher temperatures.

Corrosion Behavior of Various Metals and Alloys in Magnesium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93

Magnesium Perchlorate

Magnesium perchlorate, ($Mg(ClO_4)_2 \cdot 6H_2O$) is a white deliquescent crystal; soluble in water and alcohol and explosive when in contact with reducing materials. It is used as a drying agent for gases.

Corrosion Behavior of Various Metals and Alloys in Magnesium Perchlorate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
AP65	...	...	1M solution	22	22 (72)	5 h	200 (7960)	...	246

(Continued)

Corrosion Behavior of Various Metals and Alloys in Magnesium Perchlorate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
AP65	...	...	2M solution	45	22 (72)	5 h	142 (5680)	...	246
AZ31B	...	...	1M solution	22	22 (72)	5 h	18 (735)	...	246
AZ31B	...	...	2M solution	45	22 (72)	5 h	8.4 (334)	...	246
AZ61A	M11601	...	1M solution	22	22 (72)	5 h	54 (2175)	...	246
AZ61A	M11601	...	2M solution	45	22 (72)	5 h	13 (507)	...	246
Magnesium	...	...	1M solution	22	22 (72)	5 h	515 (20655)	...	246
Magnesium	...	...	2M solution	45	22 (72)	5 h	255 (10230)	...	246

Magnesium Sulfate

Magnesium sulfate ($MgSO_4$) is a colorless crystal with a bitter, saline taste. It is soluble in glycerol and used in fireproofing, textile processes, ceramics, cosmetics, and fertilizers.

Corrosion Behavior of Various Metals and Alloys in Magnesium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
High purity lead	L50001	...	...	100	8 (46)	...	.01 (0.3)	...	254
Stainless steels									
301	S30100	...	...	Concentrated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Concentrated	Boiling	...	Resistant	...	253
302	S30200	...	...	Concentrated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Concentrated	Boiling	...	Resistant	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Good	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	Boiling	...	Resistant	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Concentrated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Concentrated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Concentrated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	Boiling	...	Resistant	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Concentrated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Concentrated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Magnesium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	Concentrated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	Boiling	...	Resistant	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Concentrated	Boiling	...	Resistant	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	Boiling	...	Resistant	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Concentrated	Boiling	...	Resistant	...	253
403	S40300	...	...	Concentrated	20 (68)	...	Questionable	...	253
405	S40500	...	...	Concentrated	20 (68)	...	Questionable	...	253
409	S40900	...	...	Concentrated	20 (68)	...	Questionable	...	253
410	S41000	...	...	Concentrated	20 (68)	...	Questionable	...	253
416	S41600	...	...	Concentrated	20 (68)	...	Questionable	...	253
420	S42000	...	...	Concentrated	20 (68)	...	Questionable	...	253
430	S43000	...	...	Concentrated	20 (68)	...	Good	...	253
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	Boiling	...	Resistant	...	253

Maleic Acid

Maleic acid, HOOCCH:CHCOOH, also known as maleinic acid and toxilic acid, is a colorless crystalline dibasic acid with a melting point of 130 °C (266 °F). It is soluble in water and alcohol. Maleic acid is used in manufacturing synthetic resins, in textile processing, and in preserving oils and fats.

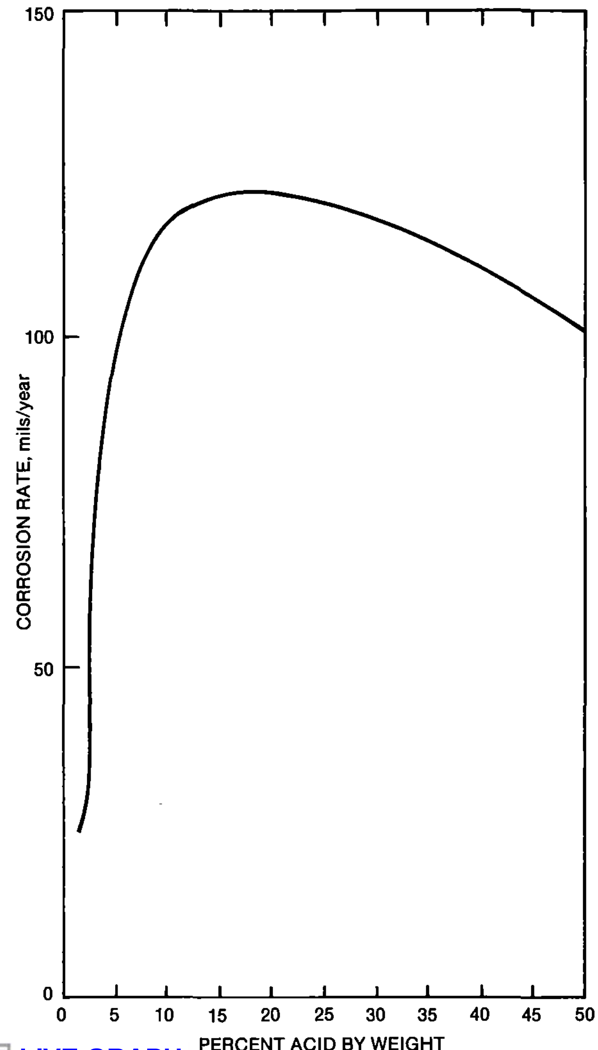
Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Under laboratory conditions of ambient temperature and 100% relative humidity, aluminum alloys 3003 and 5154 were resistant to solid maleic acid. In other laboratory tests, aluminum alloy 1100 endured mild attack (1.25 mm/yr, or 5 mils/yr) by 30% aqueous maleic acid solutions at 52 °C (126 °F) and corrosion at 100 °C (212 °F).

Corrosion Behavior of Various Metals and Alloys in Maleic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	Nonaerated solutions	...	20 (68)	...	Resistant	...	94
Refractory metals and alloys									
Titanium	...	...	...	18-20	35 (95)	...	0.002 (0.08)	...	90
Titanium, unalloyed	...	...	...	20	35 (95)	...	.005 (0.2) max	...	218



LIVE GRAPH
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Aluminum. Effect of maleic acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 25.

Malic Acid

Malic acid, HOOCCH(OH)·CH_2COOH, also known as hydroxysuccinic acid, is a colorless solid. It is soluble in water and alcohol. Malic acid exists in two optically active forms and a racemic mixture. It is used in medicine and found in apples and other fruits.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Corrosion Behavior of Various Metals and Alloys in Malic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum-manganese alloys	...	...	...	...	...	...	Resistant	...	92
Stainless steels									
301	S30100	...	...	Up to 50	20 (68)	...	Resistant	...	253
301	S30100	...	...	Up to 50	50 (122)	...	Resistant	...	253
301	S30100	...	...	Up to 50	100 (212)	...	Resistant	...	253
302	S30200	...	...	Up to 50	20 (68)	...	Resistant	...	253
302	S30200	...	...	Up to 50	50 (122)	...	Resistant	...	253
302	S30200	...	...	Up to 50	100 (212)	...	Resistant	...	253
303	S30300	...	...	Up to 50	20 (68)	...	Resistant	...	253
303	S30300	...	...	Up to 50	20 (68)	...	Resistant	...	253
303	S30300	...	...	Up to 50	50 (122)	...	Resistant	...	253
303	S30300	...	...	Up to 50	50 (122)	...	Resistant	...	253
303	S30300	...	...	Up to 50	100 (212)	...	Resistant	...	253
303	S30300	...	...	Up to 50	100 (212)	...	Resistant	...	253
304	S30400	...	...	Up to 50	20 (68)	...	Resistant	...	253
304	S30400	...	...	Up to 50	50 (122)	...	Resistant	...	253
304	S30400	...	...	Up to 50	100 (212)	...	Resistant	...	253
304	S30400	...	Food processing; field or plant test; no aeration; no agitation. Apple sauce, plus 21% soluble solids (mostly sugars), trace sodium chloride, pH 3.4-3.7, temperature initially 102°C (216°F)	0.33-0.55	Room	57 d	0.003 (0.1) max	...	89
304	S30400	...	Food processing; field or plant test; no aeration; rapid agitation. Concentrated apple juice, plus 72% soluble solids (mostly sugars), pH 3.3-3.45 (Majonnier vacuum pan)	2.1-2.7	57 (135)	42 d	0.003 (0.1) max	...	89
304	S30400	...	Food processing; field or plant test; strong aeration; slight to moderate agitation. Fresh apple juice, plus 12-14% soluble solids (mostly sugars), pH 3.55-3.65 (tank bottom)	0.35-0.45	10-29 (50-85)	42 d	0.003 (0.1) max	...	89
304	S30400	...	Food processing; field or plant test; strong aeration; slight to moderate agitation. Hard cider, plus 6.5-7.5% alcohol, 0.2-0.4% acetic acid, pH 3.55-3.65	0.35-0.45	18 (65)	88 d	0.003 (0.1) max	...	89
304L	S30403	...	...	Up to 50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Up to 50	50 (122)	...	Resistant	...	253
304L	S30403	...	...	Up to 50	100 (212)	...	Resistant	...	253
304LN	S30453	...	...	Up to 50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Up to 50	50 (122)	...	Resistant	...	253
304LN	S30453	...	...	Up to 50	100 (212)	...	Resistant	...	253
316	S31600	...	...	Up to 50	20 (68)	...	Resistant	...	253
316	S31600	...	...	Up to 50	50 (122)	...	Resistant	...	253
316	S31600	...	...	Up to 50	100 (212)	...	Resistant	...	253
316	S31600	...	Food processing; field or plant test; no aeration; no agitation. Apple sauce, plus 21% soluble solids (mostly sugars), trace sodium chloride, pH 3.4-3.7, temperature initially 102°C (216°F)	0.33-0.55	Room	57 d	0.003 (0.1) max	...	89

(Continued)

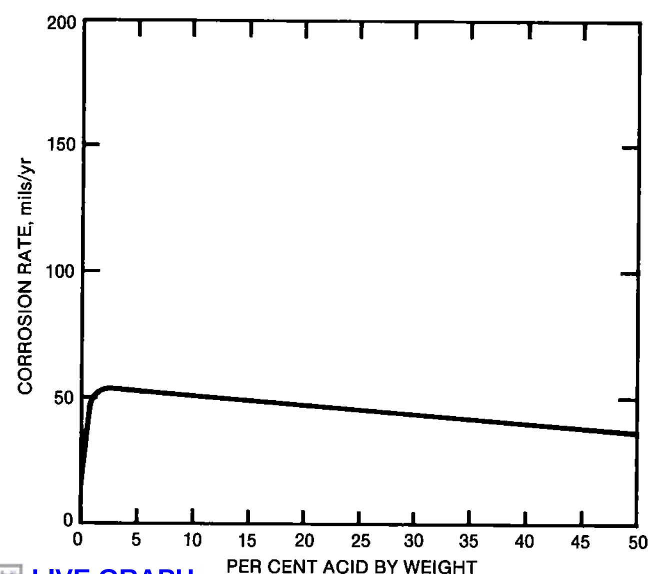
Corrosion Behavior of Various Metals and Alloys in Malic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Food processing; field or plant test; no aeration; rapid agitation. Concentrated apple juice, plus 72% soluble solids (mostly sugars), pH 3.3-3.45 (Majonnier vacuum pan)	2.1-2.7	57 (135)	42 d	0.003 (0.1) max	...	89
316	S31600	...	Food processing; field or plant test; strong aeration; slight to moderate agitation. Fresh apple juice, plus 12-14% soluble solids (mostly sugars), pH 3.55-3.65 (tank bottom)	0.35-0.45	10-29 (50-85)	42 d	0.003 (0.1) max	...	89
316	S31600	...	Food processing; field or plant test; strong aeration; slight to moderate agitation. Hard cider, plus 6.5-7.5% alcohol, 0.2-0.4% acetic acid, pH 3.55-3.65	0.35-0.45	18 (65)	88 d	0.003 (0.1) max	...	89
316F	S31620	...	...	Up to 50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Up to 50	50 (122)	...	Resistant	...	253
316F	S31620	...	...	Up to 50	100 (212)	...	Resistant	...	253
316L	S31603	...	...	Up to 50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Up to 50	50 (122)	...	Resistant	...	253
316L	S31603	...	...	Up to 50	100 (212)	...	Resistant	...	253
316LN	S31653	...	...	Up to 50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Up to 50	50 (122)	...	Resistant	...	253
316LN	S31653	...	...	Up to 50	100 (212)	...	Resistant	...	253
316Ti	S31635	...	...	Up to 50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Up to 50	50 (122)	...	Resistant	...	253
316Ti	S31635	...	...	Up to 50	100 (212)	...	Resistant	...	253
317L	S31703	...	...	Up to 50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Up to 50	50 (122)	...	Resistant	...	253
317L	S31703	...	...	Up to 50	100 (212)	...	Resistant	...	253
317LN	S31725	...	...	Up to 50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Up to 50	50 (122)	...	Resistant	...	253
317LN	S31725	...	...	Up to 50	100 (212)	...	Resistant	...	253
321	S32100	...	...	Up to 50	20 (68)	...	Resistant	...	253
321	S32100	...	...	Up to 50	50 (122)	...	Resistant	...	253
321	S32100	...	...	Up to 50	100 (212)	...	Resistant	...	253
329	S32900	...	...	Up to 50	20 (68)	...	Resistant	...	253
329	S32900	...	...	Up to 50	50 (122)	...	Resistant	...	253
329	S32900	...	...	Up to 50	100 (212)	...	Resistant	...	253
347	S34700	...	...	Up to 50	20 (68)	...	Resistant	...	253
347	S34700	...	...	Up to 50	50 (122)	...	Resistant	...	253
347	S34700	...	...	Up to 50	100 (212)	...	Resistant	...	253
403	S40300	...	...	Up to 50	20 (68)	...	Resistant	...	253
403	S40300	...	...	Up to 50	50 (122)	...	Resistant	...	253
403	S40300	...	...	Up to 50	100 (212)	...	Resistant	...	253
405	S40500	...	...	Up to 50	20 (68)	...	Resistant	...	253
405	S40500	...	...	Up to 50	50 (122)	...	Resistant	...	253
405	S40500	...	...	Up to 50	100 (212)	...	Resistant	...	253
409	S40900	...	...	Up to 50	20 (68)	...	Resistant	...	253
409	S40900	...	...	Up to 50	50 (122)	...	Resistant	...	253
409	S40900	...	...	Up to 50	100 (212)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	Up to 50	20 (68)	...	Resistant	...	253
410	S41000	...	...	Up to 50	50 (122)	...	Resistant	...	253
410	S41000	...	...	Up to 50	100 (212)	...	Resistant	...	253
416	S41600	...	...	Up to 50	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Malic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	...	Up to 50	50 (122)	...	Resistant	...	253
416	S41600	...	...	Up to 50	100 (212)	...	Resistant	...	253
420	S42000	...	...	Up to 50	20 (68)	...	Resistant	...	253
420	S42000	...	...	Up to 50	50 (122)	...	Resistant	...	253
420	S42000	...	...	Up to 50	100 (212)	...	Resistant	...	253
430	S43000	...	...	Up to 50	20 (68)	...	Resistant	...	253
430	S43000	...	...	Up to 50	50 (122)	...	Resistant	...	253
430	S43000	...	...	Up to 50	100 (212)	...	Resistant	...	253
434	S43400	...	...	Up to 50	20 (68)	...	Resistant	...	253
434	S43400	...	...	Up to 50	50 (122)	...	Resistant	...	253
434	S43400	...	...	Up to 50	100 (212)	...	Resistant	...	253
F51	S31803	...	...	Up to 50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Up to 50	50 (122)	...	Resistant	...	253
F51	S31803	...	...	Up to 50	100 (212)	...	Resistant	...	253



LIVE GRAPH
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Aluminum. Effect of malic acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 33.

Manganese Sulfate

Also known as manganous sulfate, $MnSO_4 \cdot 4H_2O$ is water-soluble, translucent, efflorescent rose-red prisms which melt at 30 °C. It is used in medicine, textile printing, and ceramics, as a fungicide and fertilizer, and in paint manufacture.

Corrosion Behavior of Various Metals and Alloys in Manganese Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Manganous Chloride

$MnCl_2$ is rose-colored deliquescent crystals that are very soluble in water, and melts at 650 °C and boils at 1190 °C. The tetrahedral form, $MnCl_2.4H_2O$, melts at 58 °C and loses its water at 198 °C and is used as a catalyst in paints, dyes, pharmaceuticals, and fertilizers, and for various other purposes.

Corrosion Behavior of Various Metals and Alloys in Manganous Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	Boiling	...	Resistant	Pitting	253
301	S30100	...	...	50	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	10	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	50	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	10	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	50	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	10	Boiling	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Manganous Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	50	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	10	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	50	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	10	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	50	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	10	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	50	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	10	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	50	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	10	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	50	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	10	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	50	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	10	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	50	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	10	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	50	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	10	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	50	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	10	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	50	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	10	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	50	Boiling	...	Resistant	Pitting	253
F51	S31803	...	...	10	Boiling	...	Resistant	Pitting	253
F51	S31803	...	...	50	Boiling	...	Resistant	Pitting	253

Mercuric Acetate

Mercuric acetate, $Hg(C_2H_3O_2)_2$, is a toxic, light-sensitive white powder, soluble in water, alcohol, and acetic acid, that is used as an oxidizing agent for amines, and in the production of pharmaceutical products.

Corrosion Behavior of Various Metals and Alloys in Mercuric Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Mercuric Acetate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Mercuric Chloride

Mercuric chloride, $HgCl_2$, is white crystals that are soluble in water and alcohol that melt at 276 °C and boil at 302 °C. Highly toxic and corrosive, it is used in the manufacture of mercury compounds, in organic synthesis, as a reagent and catalyst, as a fungicide, insecticide, and wood preservative, and for many other purposes.

Corrosion Behavior of Various Metals and Alloys in Mercuric Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	0.1	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	0.1	Boiling	...	Good	Pitting	253
301	S30100	...	...	0.7	20 (68)	...	Good	...	253
301	S30100	...	...	0.7	Boiling	...	Questionable	...	253
302	S30200	...	...	0.1	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	0.1	Boiling	...	Good	Pitting	253
302	S30200	...	...	0.7	20 (68)	...	Good	...	253
302	S30200	...	...	0.7	Boiling	...	Questionable	...	253
303	S30300	...	...	0.1	20 (68)	...	Good	Pitting	253
303	S30300	...	...	0.1	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	0.1	Boiling	...	Questionable	Pitting	253
303	S30300	...	...	0.1	Boiling	...	Good	Pitting	253
303	S30300	...	...	0.7	20 (68)	...	Questionable	...	253
303	S30300	...	...	0.7	20 (68)	...	Good	...	253
303	S30300	...	...	0.7	Boiling	...	Poor	...	253
303	S30300	...	...	0.7	Boiling	...	Questionable	...	253
304	S30400	...	...	0.1	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	0.1	Boiling	...	Good	Pitting	253
304	S30400	...	...	0.7	20 (68)	...	Good	...	253
304	S30400	...	...	0.7	Boiling	...	Questionable	...	253
304L	S30403	...	...	0.1	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	0.1	Boiling	...	Good	Pitting	253
304L	S30403	...	...	0.7	20 (68)	...	Good	...	253
304L	S30403	...	...	0.7	Boiling	...	Questionable	...	253
304LN	S30453	...	...	0.1	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	0.1	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	0.7	20 (68)	...	Good	...	253
304LN	S30453	...	...	0.7	Boiling	...	Questionable	...	253
316	S31600	...	...	0.1	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	0.1	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	0.7	20 (68)	...	Good	...	253
316	S31600	...	...	0.7	Boiling	...	Questionable	...	253
316F	S31620	...	...	0.1	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	0.1	Boiling	...	Good	Pitting	253
316F	S31620	...	...	0.7	20 (68)	...	Good	...	253
316F	S31620	...	...	0.7	Boiling	...	Questionable	...	253
316L	S31603	...	...	0.1	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	0.1	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	0.7	20 (68)	...	Good	...	253
316L	S31603	...	...	0.7	Boiling	...	Questionable	...	253
316LN	S31653	...	...	0.1	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	0.1	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	0.7	20 (68)	...	Good	...	253
316LN	S31653	...	...	0.7	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	0.1	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	0.1	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	0.7	20 (68)	...	Good	...	253
316Ti	S31635	...	...	0.7	Boiling	...	Questionable	...	253
317L	S31703	...	...	0.1	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	0.1	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	0.7	20 (68)	...	Good	...	253
317L	S31703	...	...	0.7	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Mercuric Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	0.1	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	0.1	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	0.7	20 (68)	...	Good	...	253
317LN	S31725	...	...	0.7	Boiling	...	Questionable	...	253
321	S32100	...	...	0.1	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	0.1	Boiling	...	Good	Pitting	253
321	S32100	...	...	0.7	20 (68)	...	Good	...	253
321	S32100	...	...	0.7	Boiling	...	Questionable	...	253
329	S32900	...	...	0.1	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	0.1	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	0.7	20 (68)	...	Good	...	253
329	S32900	...	...	0.7	Boiling	...	Questionable	...	253
347	S34700	...	...	0.1	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	0.1	Boiling	...	Good	Pitting	253
347	S34700	...	...	0.7	20 (68)	...	Good	...	253
347	S34700	...	...	0.7	Boiling	...	Questionable	...	253
403	S40300	...	...	0.1	20 (68)	...	Questionable	Pitting	253
403	S40300	...	...	0.1	Boiling	...	Poor	Pitting	253
403	S40300	...	...	0.7	20 (68)	...	Questionable	...	253
403	S40300	...	...	0.7	Boiling	...	Poor	...	253
405	S40500	...	...	0.1	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	0.1	Boiling	...	Poor	Pitting	253
405	S40500	...	...	0.7	20 (68)	...	Questionable	...	253
405	S40500	...	...	0.7	Boiling	...	Poor	...	253
409	S40900	...	...	0.1	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	0.1	Boiling	...	Poor	Pitting	253
409	S40900	...	...	0.7	20 (68)	...	Questionable	...	253
409	S40900	...	...	0.7	Boiling	...	Poor	...	253
410	S41000	...	...	0.1	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	0.1	Boiling	...	Poor	Pitting	253
410	S41000	...	...	0.7	20 (68)	...	Questionable	...	253
410	S41000	...	...	0.7	Boiling	...	Poor	...	253
416	S41600	...	...	0.1	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	0.1	Boiling	...	Poor	Pitting	253
416	S41600	...	...	0.7	20 (68)	...	Questionable	...	253
416	S41600	...	...	0.7	Boiling	...	Poor	...	253
420	S42000	...	...	0.1	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	0.1	Boiling	...	Poor	Pitting	253
420	S42000	...	...	0.7	20 (68)	...	Questionable	...	253
420	S42000	...	...	0.7	Boiling	...	Poor	...	253
430	S43000	...	...	0.1	20 (68)	...	Good	Pitting	253
430	S43000	...	...	0.1	Boiling	...	Questionable	Pitting	253
430	S43000	...	...	0.7	20 (68)	...	Questionable	...	253
430	S43000	...	...	0.7	Boiling	...	Poor	...	253
434	S43400	...	...	0.1	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	0.1	Boiling	...	Good	Pitting	253
434	S43400	...	...	0.7	20 (68)	...	Good	...	253
434	S43400	...	...	0.7	Boiling	...	Questionable	...	253
F51	S31803	...	...	0.1	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	0.1	Boiling	...	Resistant	Pitting	253
F51	S31803	...	...	0.7	20 (68)	...	Good	...	253
F51	S31803	...	...	0.7	Boiling	...	Questionable	...	253

Mercuric Cyanide

Mercuric cyanide, $HgCl_2$, is toxic, colorless, transparent crystals that darken in light and decompose on heating. It is soluble in water and alcohol and is used as an antiseptic, in photography, and in making cyanogen.

Corrosion Behavior of Various Metals and Alloys in Mercuric Cyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Questionable	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Questionable	...	253
405	S40500	...	...	...	...	...	Questionable	...	253
409	S40900	...	...	...	...	...	Questionable	...	253
410	S41000	...	...	...	...	...	Questionable	...	253
416	S41600	...	...	...	...	...	Questionable	...	253
420	S42000	...	...	...	...	...	Questionable	...	253
430	S43000	...	...	...	...	...	Questionable	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253

Mercurous Nitrate

Mercurous nitrate, $HgNO_3 \cdot 2H_2O$, is colorless, efflorescent, light-sensitive crystals that decompose in water, and melt at 70 °C. Also known as hydrated mercurous nitrate, it is highly toxic and explosive if shocked or heated and is used as an analytical agent.

Corrosion Behavior of Various Metals and Alloys in Mercurous Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Mercurous Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Methyl Alcohol

Methyl alcohol, CH_3OH, also known as methanol or wood alcohol, is a colorless, toxic, flammable liquid with a boiling point of 64.6 °C (147 °F). The principal toxic effect is on the nervous system, particularly the retinae. Methyl alcohol is miscible in all proportions with water, ethyl alcohol, and ether. It burns with a light blue flame producing water and carbon dioxide. This vapor forms an explosive mixture (6.0 to 36.5% by volume) with air. Methyl alcohol is an important inexpensive raw material that is synthetically produced for the organic chemical industry. Nearly half of the methyl alcohol manufactured is used in the production of formaldehyde. Other uses of methyl alcohol are as an antifreeze and fuel for automobiles and as an intermediate in the production of synthetic protein.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 resists commercial methyl alcohol at all temperatures. In the same laboratory tests, the corrosion of aqueous solutions varied with their concentrations. Anhydrous methyl alcohol tested at the boiling point was corrosive. Aluminum alloy equipment has been used to process and handle methyl alcohol.

Titanium. Methyl alcohol causes stress-corrosion cracking in titanium and titanium alloys.

Zirconium. Mixtures of methyl alcohol and hydrochloric acid and mixtures of methyl alcohol and iodine cause stress-corrosion cracking of zirconium alloys.

Corrosion Behavior of Various Metals and Alloys in Methyl Alcohol

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	7
Magnesium	...	...	...	100	Room	...	Poor	...	119
Platinum	P04995	...	...	Pure	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Boiling	...	0.05 (2) max	...	10
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet	Solutions were prepared with reagent-grade chemicals	Absolute	80 (176)	7 d	Resistant	No pitting	44
Inconel 601	N06601	...	...	...	80 (176)	7 d	Resistant	...	64
Refractory metals and alloys									
Ti-3Al-2.5V, grade 9	...	...	...	100	Boiling	...	Resistant	...	91
Titanium	...	...	...	100	Boiling	...	Resistant	...	91
Titanium	...	...	...	91	35 (95)	...	Resistant	...	90
Titanium	...	...	...	95	100 (212)	...	0.01 (0.4) max	...	90
Titanium	...	...	...	99	Boiling	...	Resistant	...	33
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	65 (149)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	65 (149)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	65 (149)	...	Resistant	...	253
303	S30300	...	...	All concentrations	65 (149)	...	Resistant	...	253
304	S30400	...	...	...	21 (70)	...	Good	...	121
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	65 (149)	...	Resistant	...	253

(Continued)

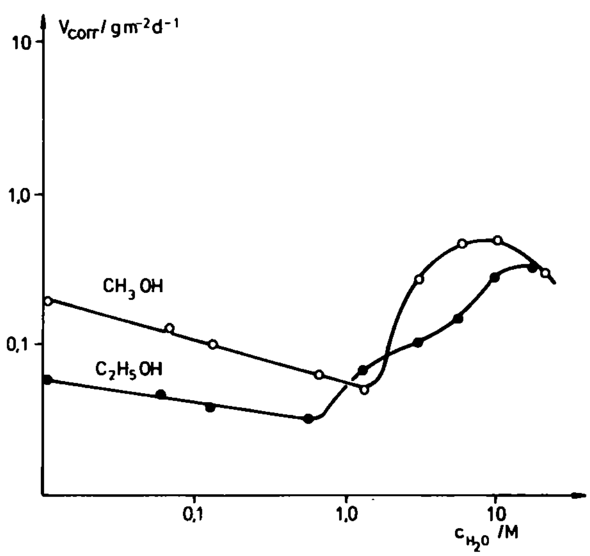
Corrosion Behavior of Various Metals and Alloys in Methyl Alcohol (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Paper (distillation) processing; slight to moderate aeration; rapid agitation. Plus ammonia, hydrogen sulfide, 1-10 g/L various mercaptans, water. and air (vapors)	15-95	82 (180)	762 d	.003 (0.1) max	Crevice attack	89
304	S30400	...	Plus 23% acetone, 15% methyl acetate, 2% water., 0.03% acetic acid, 16 psig pressure	60	74 (165)	355 d	.003 (0.1) max	...	89
304	S30400	...	Rayon processing; no aeration; rapid agitation. Plus 35% acetone, 8% 2,2-dimethoxy propane, 3% methyl acetate, 2% ethanol, 1% methylethyl ketone, 1% water	50	70 (158)	473 d	.003 (0.1) max	...	89
304	S30400	...	Rayon processing; no aeration; rapid agitation. Plus 35% acetone, 8% 2,2-dimethoxy propane, 3% methyl acetate, 2% ethanol, 1% methylethyl ketone, 1% water	50	70 (158)	473 d	Resistant	...	89
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	65 (149)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	65 (149)	...	Resistant	...	253
316	S31600	...	...	...	21 (70)	...	Resistant	...	121
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	65 (149)	...	Resistant	...	253
316	S31600	...	Chemical processing. Plus 23% acetone, 15% methyl acetate, 2% water., 0.03% acetic acid, 16 psig pressure	60	74 (165)	355 d	Resistant	...	89
316	S31600	...	Paper (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus ammonia, hydrogen sulfide, 1-10 g/L various mercaptans, water. and air (vapors)	15-95	82 (180)	762 d	.003 (0.1) max	...	89
316	S31600	...	Rayon processing; no aeration; rapid agitation. Plus 35% acetone, 8% 2,2-dimethoxy propane, 3% methyl acetate, 2% ethanol, 1% methylethyl ketone, 1% water	50	70 (158)	473 d	.003 (0.1) max	...	89
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	65 (149)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	65 (149)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	65 (149)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	65 (149)	...	Resistant	...	253
317	S31700	...	Chemical processing. Plus 23% acetone, 15% methyl acetate, 2% water., 0.03% acetic acid, 16 psig pressure	60	74 (165)	355 d	Resistant	...	89
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	65 (149)	...	Resistant	...	253

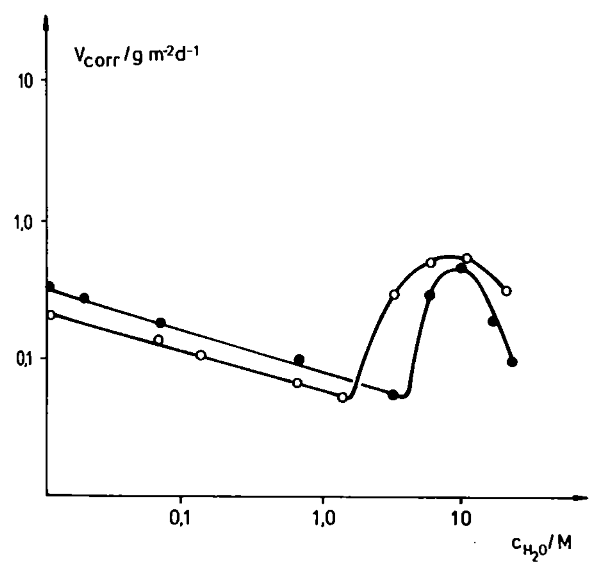
(Continued)

Corrosion Behavior of Various Metals and Alloys in Methyl Alcohol (Continued)

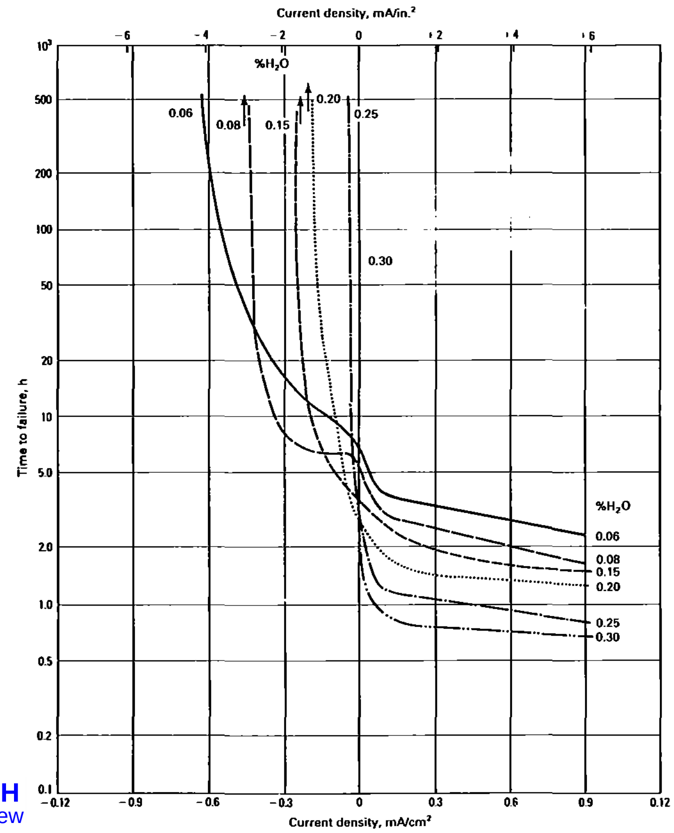
Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	65 (149)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	65 (149)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	65 (149)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	65 (149)	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	65 (149)	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	65 (149)	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	65 (149)	...	Resistant	...	253
410	S41000	...	...	...	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	65 (149)	...	Resistant	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	65 (149)	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	65 (149)	...	Resistant	...	253
430	S43000	...	...	...	21 (70)	...	Good	...	121
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	65 (149)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	65 (149)	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	65 (149)	...	Resistant	...	253



Zinc. Corrosion rates for zinc in $CH_3OH/H_2O/50$ ppm Cl^- and $C_2H_5OH/H_2O/50$ ppm Cl^-; duration of experiment 48 h, gassed with oxygen. Source: J. Banas, K.G. Schultze, *et al.*, "Corrosion Studies on Zinc in a Methanol/Water/Lithium Chloride/Oxygen System," *Journal of the Electrochemical Society*, Vol 133, Feb, 1986, 237.



Zinc. Corrosion rates for zinc in methyl alcohol solutions of differing water content, 50 ppm LiCl. Closed circle: gassed with nitrogen. Open circle: gassed with oxygen. Source: J. Banas, K.G. Schultze, *et al.*, "Corrosion Studies on Zinc in a Methanol/Water/Lithium Chloride/Oxygen System," *Journal of the Electrochemical Society*, Vol 133, Feb, 1986, 237.



LIVE GRAPH
Click here to view

Titanium. Time to failure versus applied current and water content for cold-rolled and annealed Ti-6Al-4V stressed to 75% of yield strength in a methyl alcohol/water mixture. For 0.08, 0.15, and 0.20% water, there was no failure in time shown. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 691.

Methyl Chloride

Methyl chloride, CH_3Cl, is a flammable, narcotic, colorless compressed gas or liquid with a faintly sweet odor. Slightly soluble in water and soluble in alcohol this gas boils at –23.7 °C and freezes at –97.6 °C and is used as a refrigerant, catalyst carrier, and methylating agent. Also known as chloromethane.

Corrosion Behavior of Various Metals and Alloys in Methyl Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Methyl Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253

Methylene Chloride

Also known as methylene dichloride and dichloromethane, CH_2Cl_2 is a colorless, volatile liquid with a penetrating ether-like odor that is soluble in alcohol and ether, and slightly soluble in water. Non-flammable and nonexplosive in air. Derivation is the chlorination of methyl chloride and subsequent distillation. It is used in paint removers, solvent degreasing, plastics processing. blowing agent in foams, solvent extraction, solvent for cellulose acetate, and as an aerosol propellant.

Corrosion Behavior of Various Metals and Alloys in Methylene Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Methylene Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Naphtha

Also known as petroleum ether. Naptha is a general term applied to refined, partly refined, or unrefined petroleum products and liquid products of natural gas, not less than 10% of which distill below 175 °C (347 °F) and not less than 95% of which distill below 240 °C (464 °C) when subjected to distillation in accordance with the Standard Method of Test for Distillation of Gasoline, Naphtha, Kerosene, and Similar Petroleum Products (ASTM D86). Used as a source, by various cracking processes, of gasoline, special naphthas, petroleum chemicals, especially ethylene. Cracking for ethylene also produces propylene, butadiene, pyrolysis gasoline, and fuel oil, source of synthetic natural gas.

Corrosion Behavior of Various Metals and Alloys in Naphtha

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Resistant	...	253
405	S40500	...	...	...	...	...	Resistant	...	253
409	S40900	...	...	...	...	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Methylene Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Naphtha

Also known as petroleum ether. Naptha is a general term applied to refined, partly refined, or unrefined petroleum products and liquid products of natural gas, not less than 10% of which distill below 175 °C (347 °F) and not less than 95% of which distill below 240 °C (464 °C) when subjected to distillation in accordance with the Standard Method of Test for Distillation of Gasoline, Naphtha, Kerosene, and Similar Petroleum Products (ASTM D86). Used as a source, by various cracking processes, of gasoline, special naphthas, petroleum chemicals, especially ethylene. Cracking for ethylene also produces propylene, butadiene, pyrolysis gasoline, and fuel oil, source of synthetic natural gas.

Corrosion Behavior of Various Metals and Alloys in Naphtha

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	...	...	Resistant	...	253
405	S40500	...	...	...	...	...	Resistant	...	253
409	S40900	...	...	...	...	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Naphtha (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	...	...	...	Resistant	...	253
416	S41600	...	...	...	...	...	Resistant	...	253
420	S42000	...	...	...	...	...	Resistant	...	253
430	S43000	...	...	...	...	...	Resistant	...	253
434	S43400	...	...	...	...	...	Resistant	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253

Nickel Chloride

Nickel chloride, $NiCl_2$, is a yellow deliquescent solid with a boiling point of 973 °C (1690 °F). Nickel chloride is soluble in water and alcohol. Nickel chloride (hydrated), $NiCl_2{\cdot}H_2O$, is a gray deliquescent solid that is also soluble in water and alcohol. It is used in nickel plating.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Titanium. Halide salts of oxidizing cationic species enhance the passivity of titanium alloys such that negligible corrosion rates can be expected. Examples include nickel chloride and its bromide counterparts.

Aluminum. In laboratory tests conducted under conditions of 100% relative humidity at ambient and 54 °C (130 °F) temperatures, solid nickel chloride was very corrosive to alloys 3003, 5154, and 6061 at both temperatures.

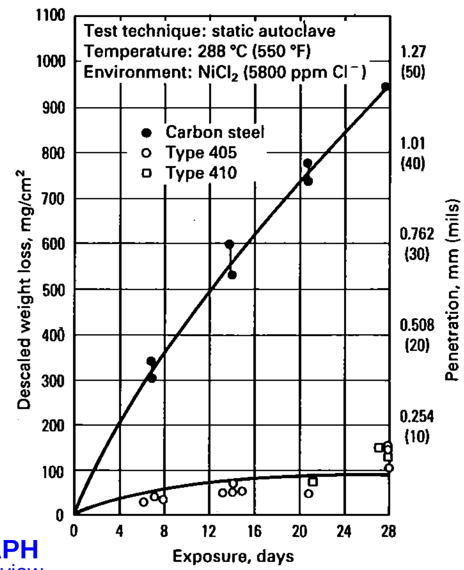
Corrosion Behavior of Various Metals and Alloys in Nickel Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Refractory metals and alloys									
Titanium	...	...	...	5	100 (212)	...	0.004 (0.16)	...	90
Titanium	...	...	...	20	100 (212)	...	0.003 (0.12)	...	90
Zr702	R60702	...	...	5	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	20	35-100 (95-212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	5-20	100 (212)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	30	Boiling	...	Resistant	...	15
Zr705	R60705	...	...	30	Boiling	...	Resistant	...	15
Refractory metals and alloys									
301	S30100	...	...	...	20 (68)	...	Good	Pitting	253
302	S30200	...	...	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Good	Pitting	253
304	S30400	...	...	...	20 (68)	...	Good	Pitting	253
304	S30400	...	Metal plating; field or plant test; no aeration; no agitation; low-carbon grade (0.03% C max). Nickel chloride solution being evaporated	...	93 (200)	26 d	0.04 (1.5)	...	89
304L	S30403	...	...	...	20 (68)	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nickel Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	...	20 (68)	...	Good	Pitting	253
316	S31600	...	...	...	20 (68)	...	Good	Pitting	253
316	S31600	...	Metal plating; field or plant test; no aeration; no agitation; low-carbon grade (0.03% C max). Nickel chloride solution being evaporated	...	93 (200)	26 d	0.03 (1.3)	...	89
316F	S31620	...	...	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Good	Pitting	253
321	S32100	...	...	...	20 (68)	...	Good	Pitting	253
329	S32900	...	...	...	20 (68)	...	Good	Pitting	253
347	S34700	...	...	...	20 (68)	...	Good	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Good	Pitting	253



LIVE GRAPH
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Steel. Corrosion of carbon steel and 12% Cr stainless steels in nickel chloride solutions. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 941.

Nickel Nitrate

Nickel nitrate, $Ni(NO_3)_2 \cdot SH_2O$, is green, monoclinic, deliquescent crystals that are soluble in water and alcohol; a dangerous fire hazard and strong oxidant that is used in nickel plating and the preparation of catalysts and brown ceramic coloring.

Corrosion Behavior of Various Metals and Alloys in Nickel Nitrate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Nickel Sulfate

Nickel sulfate, NiSO4, is either yellow-green crystals which are soluble in water and insoluble in alcohol and ether, or, blue, emerald-green, or green crystals which are soluble in water and alcohol. Derivation is by action of sulfuric acid on nickel. Used in the manufacture of nickel ammonium sulfate, nickel catalysts, nickel plating, and as a mordant in dyeing and printing textiles, coatings, and ceramics.

Corrosion Behavior of Various Metals and Alloys in Nickel Sulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nickel Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Nitric Acid

Nitric acid, HNO_3, is a strong, fire-hazardous oxidant. It is a colorless or yellowish liquid that is miscible with water and boils at 86 °C (187 °F). Nitric acid, also known as *aqua fortis*, is used for chemical synthesis, explosives, and fertilizer manufacture, and in metallurgy, etching, engraving, and ore flotation.

Nitric acid is typically produced by the air oxidation of NH_3. This catalyzed reaction takes place at very high temperatures. The gaseous oxidation product is condensed to an aqueous liquid of about 65% concentration. During the high-temperature oxidation, corrosion of the plant materials is of secondary concern. The elevated operating temperatures dictate that the high-temperature properties of the materials are the primary design consideration. Corrosion considerations prevail during and after condensation and at lower temperatures.

The concentration of nitric acid up to 99% requires secondary processing to remove excess water. This involves mixing 65% nitric acid with another substance having a greater affinity for water (such as H_2SO_4), then separating the mixed acids by distillation and condensation processes.

Commercially produced nitric acid is available in concentrations from 52 to 99%. Nitric acid over 86% is described as fuming. Nitric acid up to 95% is stored and shipped in type 304 stainless steel. Concentrated acid above 95% is handled in Aluminum Association (AA) aluminum alloys 1100 or 3003, because although the corrosion rate of type 304 stainless steel increases rapidly above 95% concentration, that of aluminum 3003 remains essentially constant to 100%. A new stainless steel containing 4% Si—alloy A-610—exhibits excellent resistance to concentrated nitric acid; unfortunately, this advantage does not extend to lower concentrations.

Nitric acid is a strong oxidizing agent and attacks most metals, such as iron, by oxidizing the metal to the oxide. A secondary effect of oxidation is the generation of hydrogen at the metal/acid interface, which can cause hydrogen embrittlement of some materials, for example, high-strength steels. Metals and alloys that are able to form adherent oxide films, such as austenitic stainless steels and aluminum alloys, are protected by their oxide films from corrosion by nitric acid.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests, the action of nitric acid on aluminum alloys varies with concentration and with temperature and is increased by agitation or by the presence of nitrogen oxide. Aluminum shows an advantage over type 304 stainless steel at acid concentrations exceeding 95%; however, if acid concentration falls below 80%, or if the temperature rises above 40 °C (100 °F), much higher corrosion rates can be expected. The preferred aluminum alloys for nitric acid service are alloy 1100 and 3003. If higher strength is required, alloys 5052 and 5454 can be used. At room temperature, the rate at which nitric acid attacks alloy 1100 exhibits a maximum at an acid concentration of 20%. At concentrations exceeding 82%, the rate of attack is between 0 and 5 mils/yr.

Aluminum alloys are widely used in storage and shipping of fuming nitric acid. When inhibited with hydrofluoric acid, red fuming nitric acid is compatible with all aluminum alloys at temperatures up to at least 71 °C (160 °F). Because solutions of the lower oxides of nitrogen, and the gases themselves, have only mild corrosive effects on aluminum alloys, these alloys have been used for catalytic oxidation of ammonia in production of nitric acid. The aluminum alloy equipment used in this process includes piping for supplying the ammonia and oxygen to the oxidizing reactor, refrigeration tanks for storage of raw materials, whirlwind gas mixers, autoclave parts, intermediate reservoirs, refining columns, heat exchangers for cooling of the acid prior to storage, and tanks and drums for storage and transportation of concentrated acid.

Cast Iron. All types of cast iron, except high-nickel austenitic iron, find some applications in nitric acid. The use of unalloyed cast iron in nitric acid is limited to low-temperature low-velocity concentrated acid service. Even in this service, caution must be exercised to avoid dilution of acid because the unalloyed and low-alloyed cast irons both corrode very rapidly in dilute or intermediate concentrations at any temperature. High-nickel austenitic cast irons exhibit essentially the same resistance as unalloyed cast iron to nitric acid and cannot be economically justified for this service.

High-chromium cast irons with chromium contents over 20% give excellent resistance to nitric acid, particularly in dilute concentrations. High-temperature boiling solutions attack these grades of cast iron. High-silicon cast irons also offer excellent resistance to nitric acid. Resistance is exhibited over essentially all concentration and temperature ranges with the exception of dilute, hot acids. High-silicon cast iron equipment has been used for many years in the manufacture and handling of nitric acid mixed with other chemicals, such as sulfuric acid, sulfates, and nitrates. Contamination of the nitric acid with HF, such as might be experienced in pickling solutions, may accelerate attack of the high-silicon iron to unacceptable levels.

Stainless Steels. Stainless steels have broad applicability in nitric acid service, primarily because of their chromium contents. Most AISI 300-series stainless steels exhibit good or excellent resistance in the annealed condition in concentrations from 0 to 65% up to the boiling point. More severe environments at elevated temperatures require alloys with higher chromium. In nitric acid cooler-condensers, such stainless alloys as 7-Mo PLUS (UNS S32950) and 2RE10 (UNS S31008), are candidates for service. Nitric acid is one of the few environments in which additions of molybdenum do not improve corrosion resistance. Thus, type 316L is inferior to type 304L in terms of resistance to nitric acid.

Corrosion of austenitic stainless steels by nitric acid is intensified by increases in temperature or acid concentration, or both. Nevertheless, there is a large useful range extending from 0 to 99% concentration and up to the boiling point below 50% concentration in which the predicted corrosion rate is less than 0.13 mm/yr (5 mils/yr). Experience has shown that, although all austenitic stainless steels behave in this fashion, types 304 and 304L, when welded, are clearly superior to the others. Therefore, they are the most popular grades for nitric acid service.

The cast equivalents of wrought stainless steels are also generally resistant to nitric acid, but the normally higher carbon contents of cast alloys and the propensity of castings to have high-carbon surfaces often lead to selective intergranular corrosion in strong nitric acid.

Although austenitic stainless steels are commonly used in nitric acid, they are not without problems. One of the most prevalent is selective corrosion associated with chromium carbides precipitated around grain boundaries in the weld heat-affected zone (sensitization). Because few pieces of industrial equipment are made without welding, this is a serious shortcoming. The most popular method of avoiding this problem is to use stainless steels of low or extra-low carbon content when welding is planned.

Sensitization of stainless steel refers to the precipitation of chromium carbides and the resultant depletion of the matrix of chromium as a result of heating from 480 to 760 °C (900 to 1400 °F). The effect of such heating on corrosion rate in 65% nitric acid is detrimental in all cases. Sigma phase, which may also form during prolonged heating of austenitic stainless steels, is preferentially and rapidly attacked by 65% nitric acid. Solution heat treating the alloy will restore corrosion resistance.

The corrosion of austenitic stainless steels in nitric acid is accompanied by the formation of hexavalent chromium (Cr^{6+}), a complex chromium compound that increases the corrosivity of nitric acid solutions. The effect of Cr^{6+} buildup is clearly detrimental. In general, the presence of chlorides and fluorides in nitric acid solutions tends to increase the corrosion rate of stainless steels.

Selective corrosion along grain boundaries is common in austenitic stainless steels exposed to nitric acid, especially strong acid. There is some evidence to support the view that this cannot be entirely prevented; however, maintaining low carbon and avoiding sensitization will help.

For very concentrated acid (>95%), the addition of silicon to iron and to austenitic stainless steels is beneficial. Cast iron with 14% Si is very resistant to acid over 50% concentration. Recently, two new stainless alloys of 4 to 6% Si—alloys A-610 and A-611—have been produced. These new alloys have remarkable resistance to nitric acid to about 95%. At lower concentrations, they offer no advantage over type 304.

Corrosion studies of sintered austenitic stainless steels have shown that corrosion resistance improves significantly with increasing density in acidic environments such as dilute sulfuric, hydrochloric, and nitric acid.

Cemented Carbides. At 50 °C (120 °F), the straight WC-Co compositions undergo rapid attack in dilute nitric acid, but little attack in concentrated acid. Cemented TiC—especially the TiC-6.5Ni-5Mo composition—has poor resistance to nitric acid. Several of the binderless compositions and the TaC-base cemented carbide exhibit quite acceptable corrosion resistance in warm nitric acid.

Copper. Aluminum bronzes are not suitable for use in nitric acid.

Lead. Nitric, acetic, and formic acids in most concentrations corrode lead at rates high enough to preclude its use in these acids. However, although nitric acid rapidly attacks lead when dilute, it has little effect at strengths of 52 to 70%.

Molybdenum. Molybdenum is rapidly attacked by oxidizing agents such as nitric acid.

Nickel. Nickel alloys are extensively used in the production of nitric acid. Alloy 617 is used for its high-temperature strength and corrosion resistance in the catalyst-support grids in high-pressure plants. In older plants, alloys 600 and 601 are used because of lower pressure. Alloy 800 is used in the heat-exchanger train. Where reboiling conditions exist, alloy 690 has given exceptional performance.

Chromium is an essential alloying element for corrosion resistance in nitric acid environments, because it readily forms a passive film in these environments. Thus, the higher chromium nickel alloys exhibit better resistance in nitric acid. In these types of environments, the highest chromium alloys, G-30 and 690, seem to exhibit the highest corrosion resistance. Molybdenum is generally detrimental to corrosion resistance in nitric acid. For example, alloy C-22 (with 13% Mo) is not as good as alloy G-3 (with 7% Mo). In pure nitric acid, stainless steels find the greatest application. In concentrated (98%) nitric acid, stainless steels containing both chromium and silicon are finding greater use. Because of the oxidizing nature of nitric acid, nitric acid streams are too severe for nickel-molybdenum alloys. The behavior of nickel-silicon alloys in nitric acid appears to depend on their microstructure and composition. Cast Hastelloy D, which consists of two phases (the nickel-silicon solid solution and the eutectic), does not show good resistance to any concentration of nitric acid. The Ni-9.5Si-2.5Cu-3Mo-2.75Ti cast alloy, which consists of a single phase, demonstrated high resistance to boiling concentrated nitric acid above 60% and to fuming (99%) nitric acid up to 80 °C (175 °F). However, the corrosion rates in more dilute acid were very high.

Niobium. Niobium is completely resistant to nitric acid in all concentrations at temperatures below 100 °C (212 °F). Even in 70% nitric acid at 250 °C (480 °F), it has a corrosion rate of only 0.025 mm/yr (1 mil/yr). In chromium plating solutions, niobium exhibits only a slight-weight change, and in the presence of small amounts of fluoride (F^-) catalyst, its corrosion resistance exceeds that of tantalum.

In one study, niobium did not exhibit stress-corrosion cracking in 90% nitric acid at room temperature using the slow strain rate technique or in liquid bromine using the U-bend testing method. However, with particular types of surface contamination and preparation, niobium, like tantalum, was found to be sensitive to crevice corrosion at anodic potentials below those normally regarded as safe. Niobium is suited for handling hot, concentrated nitric acid. It can be considered for highly oxidizing solutions expected in chemical wastes, scrubber environments, and mining solutions.

Gold. Gold is resistant to nitric acid in concentrations up to 50% at the boiling point. It is attacked by concentrated nitric acid.

Palladium. Palladium is generally resistant to corrosion by most single acids, but is attacked by nitric acid when air is present. Palladium alloys containing more than 20% Au are resistant to nitric acid. Addition of 2% Pt to palladium makes it resistant to the jewelers' nitric acid drop test used to determine equivalency with gold alloys, and addition of 10% Pt makes it completely resistant to nitric acid. Both iridium and rhodium are quite effective in improving the corrosion and tarnish resistance of palladium. Palladium alloys with 2% Ir or Rh are resistant to the nitric acid drop test.

Platinum. Up to 50% Cu can be added to platinum while still retaining its resistance to nitric acid.

Rhodium. In wrought or cast form, rhodium is unattacked at 100 °C (212 °F) by concentrated nitric acid.

Silver. Silver is attacked by nitric acid. Nitric acid that contains traces of nitrous acid attacks silver vigorously.

Tantalum. Tantalum is inert to nitric acid solutions in all concentrations and at all temperatures up to boiling. The presence of Cl^- in nitric acid does not reduce the corrosion resistance of the metal to this acid. The corrosion rate of tantalum to nitric acid at sub-boiling temperature is less than 0.4 μm/yr (0.015 mils/yr) for most concentrations and temperatures. In general, the use of tantalum at these temperatures would not be economical, considering the resistance offered by stainless steels. At temperatures near and above the normal boiling point of nitric acid, the superior resistance of tantalum becomes pronounced. Corrosion testing of tantalum for equipment to be used at these temperatures is recommended. Tantalum has been successfully used to handle fuming nitric acid at service conditions up to 5.5 MPa (800 psig) and 315 °C (600 °F) in chemical-processing equipment.

Considerable data have been accumulated on the corrosion resistance of tantalum-titanium alloys. Dilution of tantalum with titanium shows considerable promise for the possibility of providing a lower cost alloy with corrosion resistance almost comparable to that of tantalum in some select environments. In addition to dilution with a lower cost material, the resulting marked reduction in density is particularly advantageous, because corrosion applications generally require materials on a volume rather than a weight basis. Corrosion tests in 10 to 70% nitric acid at the boiling point and at 190 °C (375 °F) in sealed glass tubes were conducted on tantalum-titanium alloys ranging from pure tantalum to Ta-90Ti. All of these materials exhibited excellent behavior, with corrosion rates less than 0.025 mm/yr (1 mil/yr) and no indication of embrittlement.

Hydrogen embrittlement may occur when this alloy system is exposed to reducing corrosive conditions in tests conducted in sealed capsules. The tendency for hydrogen damage is markedly decreased as the tantalum concentration is increased.

Tin. Nitric acid reacts rapidly with tin over a wide range of concentrations, and the reaction is complex.

Titanium. Unalloyed titanium has been extensively used for handling and producing nitric acid in applications in which stainless steels have experienced significant uniform or intergranular attack. Titanium offers excellent resistance over the full concentration range at sub-boiling temperatures. As temperatures exceed 80 °C (175 °F), however, the corrosion resistance becomes highly dependent on nitric acid purity.

In hot, very pure solutions or vapor condensates of nitric acid, significant uniform corrosion rates may occur, particularly as temperatures increase. Mid-range nitric acid concentrations (20 to 70 wt%) are most aggressive when full inhibition to attack is not achieved in pure refreshed solutions. Under these conditions, semiprotective oxide surface films form that do not fully retard continued oxidation of the metal surface.

As the impurity levels increase in hot nitric acid solutions, the resistance of unalloyed titanium improves dramatically. In particular, relatively small amounts of certain dissolved metallic species, including Si^{4+}, Cr^{6+}, Fe^{3+}, Ti^{4+}, or various precious metal ions, can effectively inhibit the high-temperature corrosion of titanium in nitric acid. This inhibitive effect is very potent. Thus, titanium exhibits excellent resistance to recirculating nitric acid process streams, such as stripper reboiler loops in which steady-state levels of dissolved Ti^{4+} inhibitor are achieved. Hold

tanks and stripper sumps are also good applications for similar reasons. Another good example of this inhibitive effect is the excellent performance of unalloyed titanium in evaporator reboilers and other components in the high-temperature metal-contaminated process streams used for U_3O_8 recovery.

The significant discrepancies and variations in titanium corrosion rates in hot nitric acid media reported by investigators over the years appear to be the result of these inhibitive metal ion effects. Because titanium corrosion is inhibited by its own corrosion product (Ti^{4+}), the titanium surface area to acid volume ratio, the test duration, and the rate of solution replenishment are critical to the rate obtained. The container material and acid purity (chemistry) will also be influential. Based on this information, it is clear that all design and operating factors must be taken into account when evaluating titanium for high-temperature concentrated nitric acid service.

Limited corrosion testing of alpha-beta and beta titanium alloys in boiling nitric acid indicates that increasing aluminum and beta alloying elements tend to decrease corrosion resistance. Alpha alloys are generally most resistant to hot nitric acid. Other studies have shown that high-purity (low iron, sulfur, and so on) unalloyed titanium does not experience the significant accelerated weldment attack in high-temperature nitric acid exhibited at times by the less pure unalloyed grades and the near-alpha alloys.

Titanium alloys exhibit good resistance to white fuming nitric acid. However, dangerous and violent pyrophoric reactions may occur with titanium alloys exposed to red fuming nitric acid or to nitrogen tetroxide. The critical variables are the nitrogen dioxide (NO_2) and water contents of the acid. Fuming nitric acid containing less than 1.4 to 2% water or more than 6% NO_2 may cause this rapid impact-sensitive reaction to occur. Both water and NO are effective inhibitors for this attack, but increasing oxygen and NO_2 are detrimental in this situation.

Zirconium. Zirconium is even more resistant to nitric acid than titanium. In 98% nitric acid at temperatures below the boiling point, and in 70% nitric acid at temperatures up to 250 °C (480 °F), the corrosion rate of zirconium is less than 0.13 mm/yr (<5 mils/yr). Recent autoclave tests showed that the corrosion rates of zirconium were less than 0.025 mm/yr (<1 mil/yr) in 80% nitric acid and 90% nitric acid at 120 to 150 °C (250 and 300 °F). Moreover, the corrosion rates were still under 0.025 mm/yr (<1 mil/yr) when zirconium was tested in boiling 30 to 70% nitric acid with up to 1% $FeCl_3$, 1% NaCl, 1% seawater, 1% Fe^{3+}, or 1.45% stainless steel at 205 °C (400 °F). These results indicated that the presence of heavy-metal ions and Cl^- in nitric acid has little effect on the corrosion resistance of zirconium.

Zirconium is normally susceptible to pitting in acidic oxidizing chloride solutions. However, NO_3^- ions effectively inhibit the pitting of zirconium. The minimum ratio of NO_3^- to Cl^- required to inhibit pitting of zirconium was determined to be 1 or 5. Nevertheless, the presence of appreciable amounts of HCl should be avoided, because zirconium is not resistant to aqua regia.

Polarization curves for zirconium in nitric acid shown that a passive-to-active transition similar to that which occurs in H_2SO_4 takes place with increasing acid concentration. However, corrosion potentials are very noble because of the oxidizing nature of nitric acid. Common oxidizing agents, such as oxygen and Fe^{3+} ions, will not affect the corrosion resistance of zirconium. The polarization curves do suggest that, although corrosion rates are low, zirconium may be sensitive to stress in concentrated nitric acid. This is consistent with the observation of stress-corrosion cracking in U-bend specimens in more than 70% nitric acid. The slow strain rate technique can reveal cracking of zirconium in less than 70% nitric acid.

The primary concern in the use of zirconium for nitric acid service is cracking in concentrated nitric acid. Results of C-ring tests indicate that zirconium specimens will have a long life when they are stressed below the yield point.

Other concerns include the accumulation of chlorine gas in the vapor phase and the presence of noncomplexed F^- ions. Chlorine gas can be generated by the oxidation of chlorides by nitric acid. Areas that can trap chlorine gas should be avoided for zirconium equipment when Cl^- is present in nitric acid. Zirconium columns and reboilers are being used at one company to produce 67% nitric acid from 57% nitric acid. Previously, such materials as AISI type 304L stainless steel, titanium, and glass-lined steel were used. Titanium and type 304L stainless steel had relatively short service lives, whereas glass-lined steel presented maintenance problems.

A 27-ton zirconium heat exchanger is being used by one company to produce 65% nitric acid at 205 °C (400 °F). Before the use of zirconium, the company was faced with such problems as frequent replacement costs and downtime. In service since October 1984, the zirconium heat exchanger has already outperformed the stainless steel predecessor.

With proper design, zirconium can be used to handle a highly concentrated nitric acid. For example, an Israeli chemical plant uses zirconium tubes in a U-tube cooler that processes bleached nitric acid at concentrations between 98.5 and 99%. The unit cools the acid from 70 to 75 °C (160 to 170 °F) to 35 to 40 °C (95 to 100 °F). Previously, U-tube coolers were made from aluminum, which failed in 2 to 12 weeks. The zirconium has been in service for about 2 years, operating 24 h per day, 6 days a week.

Hafnium. Hafnium is unaffected by nitric acid in all concentrations. Hafnium alloys with 2.9, 17.3, 42.4, 59.5, and 81.4% Zr were evaluated for their corrosion resistance in various media. All of the alloys exhibited low corrosion rates (<0.0025 mm/yr, or 0.1 mil/yr) in the following boiling solutions: 30% nitric acid with or without 1% NaCl, 50% nitric acid with or without 1% NaCl, and 70% nitric acid with or without 1% NaCl. Transverse-cut U-bend specimens of these alloys were tested in 90% nitric acid at room temperature for 60 days. No cracking was observed.

Corrosion Behavior of Various Metals and Alloys in Nitric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Al-Mg_2Si	...	...	Fuming	...	...	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum (>99.5%)	A91350	...	<80% solution	...	...	...	Resistant	...	92
Aluminum (>99.5%)	A91350	...	>80% solution	...	...	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Fuming	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	<80% solution	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	>80% solution	...	...	...	Resistant	...	92
Aluminum-silicon alloys	...	...	Fuming	...	...	...	Resistant	...	92
Carbon and alloy steels									
16Ni, 8Cr, 5Si, 1Cu, 1Mo	...	...	...	25	50	102 h	0.32 (12.6)	...	206
16Ni,8Cr, 5Si, 1Cu	...	...	...	25	50	102 h	0.53 (20.7)	...	206
Carbon steel	G10100	...	...	25	Boiling	...	15,000 (600,000)	...	120
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Poor	...	93
Admiralty brass	C44300	...	...	...	...	...	Poor	...	93
Aluminum bronze	...	...	...	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Poor	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Poor	...	93
Copper	...	...	...	32	...	...	240 (9450)	...	28
Electrolytic copper	C11000	...	...	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Poor	...	93
Phosphor copper	C12200	...	...	...	...	...	Poor	...	93
Red brass	C23000	...	...	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Poor	...	93
Miscellaneous									
85WC-15Co	...	...	Tungsten carbide surface layer spalled	10	22 (72)	48 h	8.9 (355)	...	34
85WC-15Co-	...	...	Tungsten carbide surface layer spalled	10	22 (72)	48 h	8.5 (340)	...	34
94WC-6Co-	...	...	...	10	22 (72)	48 h	1.1 (45)	...	34
94WC-6Ni	...	...	...	10	22 (72)	48 h	0.4 (15)	...	34
Gold	P00016	...	...	1-50	Boiling	...	0.05 (2) max	...	8
Gold	P00016	...	...	70	Room	...	0.05 (2) min	...	8
Gold	P00016	...	...	70	Boiling	...	0.15 (6)	...	8
High purity lead	L50001	...	...	1	24 (75)	...	3.5 (140)	...	254
High purity lead	L50001	...	...	1	50 (122)	...	15 (600)	...	254
High purity lead	L50001	...	...	5	24 (75)	...	41 (1650)	...	254
High purity lead	L50001	...	...	5	50 (122)	...	46 (1850)	...	254
High purity lead	L50001	...	...	10	24 (75)	...	85 (3400)	...	254
High purity lead	L50001	...	...	10	50 (122)	...	87 (3490)	...	254

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Iridium	...	...	...	95	100 (212)	...	Resistant	...	29
Lead	L50045	...	...	1	24 (75)	...	3.5 (140)	...	130
Lead	L50045	...	...	1	50 (122)	...	15 (600)	...	130
Lead	L50045	...	...	5	24 (75)	...	41.25 (1650)	...	130
Lead	L50045	...	...	5	50 (122)	...	46.25 (1850)	...	130
Lead	L50045	...	...	10	24 (122)	...	85 (3400)	...	130
Lead	L50045	...	...	10	50 (122)	...	87.25 (3490)	...	130
Osmium	...	...	...	95	100 (212)	...	Poor	...	17
Palladium	P03980	...	...	70	Room	...	61.3 (2413)	...	17
Palladium	P03980	...	...	95	100 (212)	...	Poor	...	17
Rhodium	P05990	...	...	95	100 (212)	...	Resistant	...	29
Ruthenium	...	...	...	95	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	...	Room	...	Poor	...	4
Tin	...	...	...	25 max	20 (68)	...	Poor	...	94
Tin	...	...	...	25 max	60 (140)	...	Poor	...	94
Tin	...	...	...	25 max	100 (212)	...	Poor	...	94
Tin	...	...	...	50	20 (68)	...	Poor	...	94
Tin	...	...	...	50	50 (140)	...	Poor	...	94
Tin	...	...	...	50	100 (212)	...	Poor	...	94
Tin	...	...	...	95	20 (68)	...	Poor	...	94
Tin	...	...	...	95	60 (140)	...	Poor	...	94
Tin	...	...	...	95	100 (212)	...	Poor	...	94
Tin	...	...	Fuming	...	20 (68)	...	Resistant	...	94
Tin	...	...	Fuming	...	60 (140)	...	Resistant	...	94
Tin	...	...	Fuming	...	100 (212)	...	Resistant	...	94
Tin	...	...	Hydrogen	3	...	...	1.4 (55)	...	59
Tin	...	...	Oxygen	3	...	...	1.4 (55)	...	59
Nickel and alloys									
Allcorr	N06110	Butt welded	...	65	121 (250)	...	0.20 (7.9)	...	220
Allcorr	N06110	Butt welded	...	65	66 (151)	...	0.025 (1.0)	...	220
Allcorr	N06110	Butt welded	...	20	104 (219)	...	0.025 (1.0)	...	220
Allcorr	N06110	Butt welded	Plus 1% HF	15	104 (219)	...	0.28 (11.0)	...	220
Allcorr	N06110	Butt welded	Plus 3% HF	10	70 (158)	...	0.69 (27.2)	...	220
Allcorr	N06110	Butt welded	Plus 5% HCl	20	105 (221)	...	0.13 (5.1)	...	220
Alloy 600	N06600	...	1100°C/1 h	...	Boiling	72 h	0.04 (1.6)	...	193
Alloy 600	N06600	...	1100°C/1 h + 700°C/2 h	...	Boiling	72 h	1.8 (72)	...	193
Alloy 600	N06600	...	1100°C/1 h + 700°C/5 h	...	Boiling	72 h	1.2 (48)	...	193
Alloy 600	N06600	...	1100°C/1 h + 705°C/15 h	...	Boiling	72 h	0.3 (12)	...	193
Alloy 600	N06600	...	1120°C/0.5 h + 700°C/15 h	...	Boiling	72 h	8.7 (350)	...	193
Alloy 600	N06600	...	As received	...	Boiling	72 h	0.20 (8)	...	193
Alloy 625	N06625	Aged 24 h at 650°C	...	10	Boiling	24 h	.63 (25)	...	210
Alloy 625	N06625	Aged 100 h at 650°C	...	10	Boiling	24 h	.75 (30)	...	210
Alloy 625	N06625	Aged 500 h at 650°C	...	10	Boiling	24 h	.87 (34)	...	210
Alloy 625	N06625	Aged 1000 h at 650°C	...	10	Boiling	24 h	.88 (35)	...	210
Alloy 625	N06625	Aged 24 h at 760°C	...	10	Boiling	24 h	.80 (32)	...	210
Alloy 625	N06625	Aged 100 h at 760°C	...	10	Boiling	24 h	.90 (35)	...	210
Alloy 625	N06625	Aged 500 h at 760°C	...	10	Boiling	24 h	.98 (39)	...	210
Alloy 625	N06625	Aged 1000 h at 760°C	...	10	Boiling	24 h	.35 (14)	...	210
Alloy 625	N06625	Aged 24 h at 870°C	...	10	Boiling	24 h	.86 (34)	...	210

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 625	N06625	Aged 100 h at 870°C	...	10	Boiling	24 h	.92 (36)	...	210
Alloy 625	N06625	Aged 500 h at 870°C	...	10	Boiling	24 h	.55 (22)	...	210
Alloy 625	N06625	Aged 1000 h at 870°C	...	10	Boiling	24 h	.28 (11)	...	210
Alloy 625	N06625	...	...	60	Boiling	...	0.40 (16)	...	212
Alloy 625	N06625	Butt welded	...	65	121 (250)	...	0.41 (16.2)	Weld attack	220
Alloy 625	N06625	Butt welded	...	65	66 (151)	...	0.28 (11.0)	...	220
Alloy 625	N06625	Butt welded	...	20	104 (219)	...	0.05 (2.0)	...	220
Alloy 625	N06625	...	...	10	Boiling	...	.018 (0.7)	...	222
Alloy 625	N06625	...	Plus 1% HCl	5	Boiling	...	0.25 (1)	...	225
Alloy 625	N06625	...	Plus 1% HF	20	52 (125)	...	0.73 (29)	...	212
Alloy 625	N06625	...	Plus 1% HF	20	79 (175)	...	4.3 (171)	...	212
Alloy 625	N06625	Butt welded	Plus 1% HF	15	104 (219)	...	0.94 (37.0)	Weld attack	220
Alloy 625	N06625	...	Plus 25% H_2SO_4, 4% NaCl	5	Boiling	...	17.8 (713)	...	225
Alloy 625	N06625	...	Plus 3% HF	20	52 (125)	...	1.35 (54)	...	212
Alloy 625	N06625	...	Plus 3% HF	20	79 (175)	...	14 (565)	...	212
Alloy 625	N06625	Butt welded	Plus 3% HF	10	70 (158)	...	2.50 (99)	...	220
Alloy 625	N06625	Butt welded	Plus 5% HCl	20	105 (221)	...	0.84 (33.1)	Pitting	220
Alloy 625	N06625	...	Plus 5% HF	20	52 (125)	...	3.5 (140)	...	212
Alloy 625	N06625	...	Plus 5% HF	20	79 (175)	...	30 (1180)	...	212
Alloy 625	N06625	...	Plus 6% HF	5	60 (140)	...	1.8 (73)	...	225
Alloy 825	N08825	...	...	60	Boiling	...	0.13 (5)	...	212
Alloy 825	N08825	...	Activated	10	...	...	0.64 (25.3)	...	223
Alloy 825	N08825	...	Five 48-h exposure	65	Boiling	...	0.22 (8.8)	...	217
Alloy 825	N08825	...	Not activated	10	...	...	0.52 (20.6)	...	223
Alloy 825	N08825	...	Plus 1% HF	20	52 (125)	...	0.68 (27)	...	212
Alloy 825	N08825	...	Plus 1% HF	20	79 (175)	...	3.18 (127)	...	212
Alloy 825	N08825	...	Plus 3% HF	20	52 (125)	...	1.65 (66)	...	212
Alloy 825	N08825	...	Plus 3% HF	20	79 (175)	...	7.1 (284)	...	212
Alloy 825	N08825	...	Plus 4% HF	20	60 (140)	...	3.7 (148)	...	217
Alloy 825	N08825	...	Plus 5% HF	20	52 (125)	...	3.3 (132)	...	212
Alloy 825	N08825	...	Plus 5% HF	20	79 (175)	...	15.4 (614)	...	212
Alloy C-22	N06022	Butt welded	...	65	121 (250)	...	2.2 (87)	Weld attack	220
Alloy C-22	N06022	Butt welded	...	65	66 (151)	...	0.08 (3.2)	...	220
Alloy C-22	N06022	Butt welded	...	20	104 (219)	...	0.10 (3.9)	Weld attack	220
Alloy C-22	N06022	...	Plus 1% HCl	5	Boiling	...	0.01 (0.5)	...	225
Alloy C-22	N06022	Butt welded	Plus 1% HF	15	104 (219)	...	0.76 (30.0)	...	220
Alloy C-22	N06022	...	Plus 25% H_2SO_4, 4% NaCl	5	Boiling	...	0.3 (12)	...	225
Alloy C-22	N06022	Butt welded	Plus 3% HF	10	70 (158)	...	3.20 (126)	...	220
Alloy C-22	N06022	Butt welded	Plus 5% HCl	20	105 (221)	...	0.74 (29.2)	Weld attack	220
Alloy C-22	N06022	...	Plus 6% HF	5	60 (140)	...	1.7 (67)	...	225
Alloy C-276	N10276	Butt welded	...	65	121 (250)	...	18.0 (710)	Weld attack	220
Alloy C-276	N10276	Butt welded	...	65	66 (151)	...	0.28 (11.0)	...	220
Alloy C-276	N10276	Butt welded	...	20	104 (219)	...	0.51 (20.1)	...	220
Alloy C-276	N10276	...	...	10	Boiling	...	0.40 (16)	...	222
Alloy C-276	N10276	...	...	10	79 (175)	...	0.10 (4)	...	222
Alloy C-276	N10276	...	Plus 1% HCl	5	Boiling	...	0.20 (8)	...	225
Alloy C-276	N10276	Butt welded	Plus 1% HF	15	104 (219)	...	3.0 (120)	Weld attack	220
Alloy C-276	N10276	...	Plus 25% H_2SO_4, 4% NaCl	5	Boiling	...	1.6 (64)	...	225
Alloy C-276	N10276	Butt welded	Plus 3% HF	10	70 (158)	...	5.4 (213)	Weld attack	220
Alloy C-276	N10276	Butt welded	Plus 5% HCl	20	105 (221)	...	5.10 (200)	Weld attack	220
Alloy C-276	N10276	...	Plus 6% HF	5	60 (140)	...	5.2 (207)	...	225
Alloy C-4	N06455	...	Plus 1% HCl	5	Boiling	...	0.27 (11)	...	225

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy C-4	N06455	...	Plus 25% H_2SO_4, 4% NaCl	5	Boiling	...	2.4 (97)	...	225
Alloy C-4	N06455	...	Plus 6% HF	5	60 (140)	...	5.1 (204)	...	225
Alloy G	N06007	...	...	65	Boiling	...	0.30 (12)	...	225
Alloy G	N06007	...	Five 48-h exposure	65	Boiling	...	0.30 (12.0)	...	217
Alloy G-3	N06985	...	...	65	Boiling	...	0.28 (11)	...	212
Alloy G-3	N06985	...	Plus 0.5% HF	56	100 (212)	...	3.38 (135)	...	225
Alloy G-3	N06985	...	Plus 1% HF	20	52 (126)	...	0.48 (19)	...	212
Alloy G-3	N06985	...	Plus 1% HF	20	79 (174)	...	1.65 (66)	...	212
Alloy G-30	N06030	...	...	65	...	...	0.13 (5)	...	212
Alloy G-30	N06030	...	...	60	Boiling	...	0.13 (5)	...	212
Alloy G-30	N06030	...	Plus 1% HF	...	...	...	0.20 (8)	...	212
Alloy G-30	N06030	...	Plus 1% HF	...	79 (174)	...	0.45 (18)	...	212
Alloy G-30	N06030	...	Plus 1% HF	20	52 (125)	...	2.13 (85)	...	212
Alloy G-30	N06030	...	Plus 1% HF	20	79 (175)	...	0.45 (18)	...	212
Alloy G-30	N06030	...	Plus 3% HF	20	52 (125)	...	0.45 (18)	...	212
Alloy G-30	N06030	...	Plus 3% HF	20	79 (175)	...	1.28 (51)	...	212
Alloy G-30	N06030	...	Plus 5% HF	20	52 (125)	...	0.73 (29)	...	212
Alloy G-30	N06030	...	Plus 5% HF	20	79 (175)	...	4.0 (158)	...	212
Carpenter Pyromet Alloy 102	...	Stress relieved at 843°C (1550°F) for 30 min furnace cooled	Plus 3% HF	15	...	48 h	4.3 (172)	...	30
Carpenter Pyromet Alloy 102	...	...	Plus 3% HF, annealed	15	...	48 h	4.3 (172)	...	30
Hastelloy G-30	N06030	...	...	65	Boiling	...	0.10 (4)	...	225
Hastelloy G-30	N06030	...	...	56	100 (212)	...	1.30 (52)	...	225
Inco alloy G	N06007	...	...	65	Boiling	...	22 (0.56)	...	40
Inco alloy G-3	N06985	...	Huey test (ASTM Practice A-262-C) results	65	Boiling	...	14 (0.36)	...	40
Inco alloy G-3	N06985	...	Huey test (ASTM Practice A-262-C) results	65	Boiling	...	16 (0.41)	...	40
Inconel 601	N06601	...	...	5	Boiling	72 h	0.002 (0.1)	...	64
Inconel 601	N06601	...	...	10	Boiling	72 h	0.005 (0.2)	...	64
Inconel 601	N06601	...	...	20	Boiling	72 h	0.018 (0.7)	...	64
Inconel 601	N06601	...	...	30	Boiling	72 h	0.030 (1.2)	...	64
Inconel 601	N06601	...	...	40	Boiling	72 h	0.046 (1.8)	...	64
Inconel 601	N06601	...	...	50	Boiling	72 h	0.061 (2.4)	...	64
Inconel 601	N06601	...	...	60	Boiling	72 h	0.130 (5.1)	...	64
Inconel 601	N06601	...	...	70	Boiling	72 h	0.193 (7.6)	...	64
Inconel 617	N06617	...	Plus 2% HF	20	60 (140)	...	0.15 (6)	...	57
Inconel 617	N06617	...	Plus 3% HF	10	60 (140)	...	0.15 (6)	...	57
Inconel 617	N06617	...	Plus 3% HF	15	60 (140)	...	0.25 (10)	...	57
MP35N	R30035	...	...	10	Boiling	24 h	0.056 (2.2)	...	23
Nickel	N02200	...	...	1*N*	25 (75)	...	19 (770)	...	35
Nickel-20Cr	...	...	...	11	Hot	...	Resistant	...	35
Sanicro 28	N08028	...	...	60	Boiling	...	0.10 (4)	...	212
Sanicro 28	N08028	...	Five 48-h exposure	65	Boiling	...	0.06 (2.4)	...	217
Sanicro 28	N08028	...	Plus 1% HF	20	52 (125)	...	0.23 (9)	...	212
Sanicro 28	N08028	...	Plus 1% HF	20	79 (175)	...	0.98 (39)	...	212
Sanicro 28	N08028	...	Plus 3% HF	20	52 (125)	...	0.50 (20)	...	212
Sanicro 28	N08028	...	Plus 3% HF	20	79 (175)	...	2.3 (91)	...	212
Sanicro 28	N08028	...	Plus 4% HF	20	60 (140)	...	0.07 (28)	...	217
Sanicro 28	N08028	...	Plus 5% HF	20	52 (125)	...	0.85 (34)	...	212
Sanicro 28	N08028	...	Plus 5% HF	20	79 (175)	...	4.3 (172)	...	212
Refractory metals and alloys									
44-Co-31Cr-13W	...	As cast. Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.15 (6)	...	53

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
44-Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.15 (6)	...	53
44-Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.05 (2)	...	53
44-Co-31Cr-13W	...	As cast. Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.8 (32)	...	53
50Co-20Cr-15W-10Ni	...	...	...	10	Boiling	...	0.012 (0.5)	...	53
50Co-20Cr-15W-10Ni	...	...	...	40	65 (150)	...	0.012 (0.5)	...	53
50Co-20Cr-15W-10Ni	...	Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.012 (0.5)	...	53
50Co-20Cr-15W-10Ni	...	As cast. Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.012 (0.5)	...	53
53-Co-30Cr-4.5W	...	As cast. Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.02 (0.8)	...	53
53-Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.025 (1)	...	53
53-Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimens	Based on five 24-h test periods	10	Boiling	...	0.025 (1)	...	53
53-Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.007 (0.3)	...	53
53-Co-30Cr-4.5W	...	As cast, Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.005 (0.2)	...	53
53-Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast specimens	Based on five 24-h test periods	40	65 (150)	...	0.007 (0.3)	...	53
67Zr-33Ni	...	Crystalline	...	...	22-25	600 h	.001 (.04)	...	204
67Zr-33Ni	...	Amorphous	...	...	22-25	600 h	.001 (.04) max	...	204
Cb alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 0.75%Zr bal Cb. Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Cb alloy	...	Arc melted	Wrought 50% V, 50% Cb. Average of three 48-h periods	65	Boiling	48 h	0.43 (17)	...	38
Cb alloy	...	Arc melted; annealed at 1430°C (2606°F) for 1 h	Wrought 6.9% Ti, 0.81% Zr, bal Cb. Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Cb alloy	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Wrought 8% Ti, bal Cb. Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Co-20Cr	...	...	...	11	Boiling	...	Resistant	...	35
Co-Cr-Ni	R31233	Welding rod	...	65	Boiling	...	0.15 (6)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with G10400	...	65	Boiling	...	0.30 (12)	...	196
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	65	Boiling	...	0.25 (10)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with S31603	...	65	Boiling	...	0.30 (12)	...	196
Co-Cr-Ni	R31233	Diluted 16.7% with S31603	...	65	Boiling	...	0.23 (9)	...	196
Cobalt	...	...	...	1*N*	25 (75)	...	223 (8900)	...	35
Hafnium	...	...	...	30	...	8 d	Resistant	...	11
Hafnium	...	...	...	50	...	8 d	Resistant	...	11
Hafnium	...	...	...	70	...	8 d	Resistant	...	11
Hafnium	...	...	...	70	...	8 d	Resistant	...	11

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hafnium	...	...	Plus 1% NaCl	30	...	8 d	Resistant	...	11
Hafnium	...	...	Plus 1% NaCl	50	...	8 d	Resistant	...	11
Hafnium	...	...	Plus 1% NaCl	70	...	8 d	Resistant	...	11
Havar	R30004	...	...	10	Boiling	24 h	0.066 (2.6)	...	23
Haynes No. 188	R30188	...	...	10	Boiling	24 h	0.02 (0.8)	...	23
Haynes No. 188	R30188	...	Based on an average of five 24-h test periods	65	Boiling	24 h	0.56 (22)	...	23
Haynes No. 21	R30021	...	...	10	Boiling	24 h	0.025 (1.0)	...	23
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	10	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	10	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	10	Boiling	24 h	0.02 (0.5) max	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	20	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	20	66 (150)	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	20	Boiling	24 h	0.05 (2.0)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	30	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	30	66 (150)	24 h	0.01 (0.3) max	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	30	Boiling	24 h	0.10 (4.0)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	40	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	40	66 (150)	24 h	0.02 (0.5) max	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	40	Boiling	24 h	0.23 (9.0)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	50	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	50	66 (150)	24 h	0.02 (0.8)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	50	Boiling	24 h	0.46 (18)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	60	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	60	66 (150)	24 h	0.05 (2.0)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	60	Boiling	24 h	0.86 (34)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	65	Boiling	24 h	1.04 (41)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	70	Room	24 h	Resistant	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	70	66 (150)	24 h	0.05 (2.0)	...	68
Haynes No. 25	R30605	...	Calculated on a minimum of five 24-h test periods	70	Boiling	24 h	1.17 (46)	...	68
Haynes No. 556	R30556	...	Based on an average of five 24-h test periods	65	Boiling	24 h	0.28 (11)	...	23
Haynes No. 6B	...	...	...	10	Boiling	24 h	0.023 (0.9)	...	23
Haynes No. 6B	...	...	...	70	Boiling	24 h	96.5 (3800)	...	23
Magnesium	...	...	...	All	Room	...	Poor	...	119
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	10	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	10	66 (150)	24 h	Resistant	...	68

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	10	Boiling	24 h	0.01 (0.3) max	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	20	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	20	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	20	Boiling	24 h	0.02 (0.8)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	30	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	30	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	30	Boiling	24 h	0.05 (2.0)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	40	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	40	66 (150)	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	40	Boiling	24 h	0.10 (4.0)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	50	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	50	66 (150)	24 h	0.01 (0.3) max	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	50	Boiling	24 h	0.15 (6.0)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	60	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	60	66 (150)	24 h	0.01 (0.4)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	60	Boiling	24 h	0.25 (10)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	65	Boiling	24 h	0.30 (12)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	70	Room	24 h	Resistant	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	70	66 (150)	24 h	0.02 (0.8)	...	68
Multimet	R30155	...	Calculated on a minimum of five 24-h test periods	70	Boiling	24 h	0.36 (14)	...	68
Niobium	R04210	...	...	1	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	1	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	10	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	10	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	20	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	30	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	30	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	40	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	40	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	50	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	50	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	60	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	60	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	65	Room	...	Resistant	...	2
Niobium	R04210	...	...	65	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	65	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	70	Boiling	...	0.07 (3) max	...	37
Niobium	R04210	...	...	70	190 (375)	...	0.07 (3) max	...	37
Niobium	R04210	...	...	70	250 (480)	...	0.025 (1.0)	...	2
Niobium	R04210	...	...	Concentrated	19-26 (65-80)	36 d	Resistant	...	74

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium	R04210	Annealed at 1175°C (2140°F) for 30 min	Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Niobium	R04210	Electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Tantalum	R05210	...	...	Concentrated	19-26 (65-80)	39 d	Resistant	...	74
Tantalum	R05210	...	...	1	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	1	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	20	100 (212)	...	Resistant	...	42
Tantalum	R05210	...	...	20	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	20	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	30	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	30	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	40	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	40	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	50	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	50	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	60	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	60	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	65	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	65	170 (338)	...	0.0254 (1) max	...	42
Tantalum	R05210	...	...	65	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	70	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	70	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	70	100 (212)	...	Resistant	...	42
Tantalum, commercial sheet	R05210	...	Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Tantalum, high purity	R05210	...	Average of three 48-h periods	65	Boiling	48 h	0.025 (1) max	...	38
Ti-10-2-3	...	...	...	25	Boiling	196 h	0.5 (19)	...	27
Ti-10-2-3	...	...	...	45	Boiling	196 h	1.2 (47)	...	27
Ti-10-2-3	...	...	...	70	Boiling	196 h	0.07 (2.8)	...	27
Ti-3-8-6-4-4	R58640	...	...	25	Boiling	196 h	1.1 (45)	...	27
Ti-3-8-6-4-4	R58640	...	...	45	Boiling	196 h	3.6 (142)	...	27
Ti-3-8-6-4-4	R56840	...	...	70	Boiling	196 h	1.5 (58)	...	27
Ti-550	...	...	...	25	Boiling	196 h	0.83 (33)	...	27
Ti-550	...	...	...	45	Boiling	196 h	1.1 (45)	...	27
Ti-550	...	...	...	70	Boiling	196 h	0.30 (12)	...	27
Ti-5Ta	...	...	...	25	Boiling	196 h	0.04 (1.6)	...	27
Ti-5Ta	...	...	...	45	Boiling	196 h	0.08 (3.1)	...	27
Ti-5Ta	...	...	...	70	Boiling	196 h	0.03 (1.2)	...	27
Ti-6-2-1-0.8	...	...	...	25	Boiling	196 h	0.39 (15)	...	27
Ti-6-2-1-0.8	...	...	...	45	Boiling	196 h	0.73 (29)	...	27
Ti-6-2-1-0.8	...	...	...	70	Boiling	196 h	0.21 (8.3)	...	27
Ti-6-2-4-6	R56260	...	...	25	Boiling	196 h	4.3 (170)	...	27
Ti-6-2-4-6	R56260	...	...	45	Boiling	196 h	5.7 (224)	...	27
Ti-6-2-4-6	R56260	...	...	70	Boiling	196 h	0.78 (31)	...	27
Titanium	...	...	...	Concentrated	19-26 (65-80)	36 d	0.001 (0.05)	...	74
Titanium	...	...	...	10	Boiling	...	0.11 (4.4)	...	91
Titanium	...	...	...	17	Boiling	...	0.10 (4.1) max	...	90

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	...	20	Boiling	...	0.2 (8.0)	...	91
Titanium	...	...	...	30	Boiling	...	0.5 (20.0)	...	91
Titanium	...	...	...	35	Boiling	...	0.51 (20) max	...	90
Titanium	...	...	...	35	80 (176)	...	0.10 (4.1) max	...	90
Titanium	...	...	...	40	Boiling	...	0.61 (24)	...	91
Titanium	...	...	...	40	Boiling	...	0.63 (25)	...	91
Titanium	...	...	...	50	Boiling	...	0.61 (25)	...	91
Titanium	...	...	...	60	Boiling	...	0.39 (16)	...	91
Titanium	...	...	...	65	204 (399)	...	0.005 (0.2)	...	91
Titanium	...	...	...	70	Boiling	...	0.13 (5.2)	...	91
Titanium	...	...	...	70	80 (176)	...	0.076 (3.04) max	...	90
Titanium	...	...	...	70	Boiling	...	0.9 (36) max	...	90
Titanium	...	...	Aerated	10	Room	...	0.005 (0.2)	...	90
Titanium	...	...	Aerated	10	40 (104)	...	0.003 (0.12)	...	90
Titanium	...	...	Aerated	20	40 (104)	...	0.005 (0.2)	...	90
Titanium	...	...	Aerated	20	290 (554)	...	0.31 (12)	...	90
Titanium	...	...	Aerated	30	Room	...	0.004 (0.16)	...	90
Titanium	...	...	Aerated	30	50 (122)	...	0.015 (0.6)	...	90
Titanium	...	...	Aerated	40	200 (392)	...	0.610 (24)	...	90
Titanium	...	...	Aerated	40	Room	...	0.002 (0.08)	...	90
Titanium	...	...	Aerated	40	50 (122)	...	0.016 (0.64)	...	90
Titanium	...	...	Aerated	50	Room	...	0.002 (0.08)	...	90
Titanium	...	...	Aerated	50	60 (140)	...	0.037 (1.5)	...	90
Titanium	...	...	Aerated	60	Room	...	0.001 (0.04)	...	90
Titanium	...	...	Aerated	60	60 (140)	...	0.040 (1.6)	...	90
Titanium	...	...	Aerated	70	Room	...	0.005 (0.2)	...	90
Titanium	...	...	Aerated	70	70 (158)	...	0.040 (1.6)	...	90
Titanium	...	...	Aerated	70	270 (518)	...	1.22 (48.8)	...	90
Titanium	...	...	Not refreshed	5-20	100 (212)	...	0.02 (0.8)	...	90
Titanium	...	...	Not refreshed	5-60	35 (95)	...	0.007 (0.28) max	...	90
Titanium	...	...	Not refreshed	5-60	60 (140)	...	0.02 (0.8) max	...	90
Titanium	...	...	Not refreshed	20	290 (554)	...	0.4 (16)	...	90
Titanium	...	...	Not refreshed	30-50	100 (212)	...	0.18 (7.2) max	...	90
Titanium	...	...	Not refreshed	30-60	190 (374)	...	2.8 (112) max	...	90
Titanium	...	...	Not refreshed	70	270 (518)	...	1.2 (48)	...	90
Titanium	...	...	Not refreshed	70	290 (554)	...	1.1 (44)	...	90
Titanium	...	...	Plus 0.01% CrO_3	40	Boiling	...	0.01 (0.4)	...	90
Titanium	...	...	Plus 0.01% $FeCl_3$	40	Boiling	...	0.68 (27)	...	90
Titanium	...	...	Plus 0.01% $K_2Cr_2O_7$	40	Boiling	...	0.01 (0.4)	...	90
Titanium	...	...	Plus 0.1% $K_2Cr_2O_7$	40	Boiling	...	0.016 (0.64)	...	90
Titanium	...	...	Plus 1% $Ce(SO_4)_2$	40	Boiling	...	0.10 (4)	...	90
Titanium	...	...	Plus 1% $FeCl_3$	40	Boiling	...	0.14 (5.6)	...	90
Titanium	...	...	Plus 1% $NaClO_3$	40	Boiling	...	0.31 (12)	...	90
Titanium	...	...	Plus 1% $NaClO_3$	40	Boiling	...	0.02 (0.8)	...	90
Titanium	...	...	Plus 15% zirconyl nitrate	65	127 (261)	...	Resistant	...	90
Titanium	...	...	Plus 170 g/L $NaNO_3$ + 2.9 g/L NaCl	27.4	Boiling	...	19 (117) max	...	90
Titanium	...	...	Plus 179 g/L $NaNO_3$ + 32 g/L NaCl	20.8	Boiling	...	0.30 (12) max	...	90
Titanium	...	...	Plus 5% HF	35	25 (77)	...	450 (18)	...	90
Titanium	...	...	Plus 5% HF	35	35 (95)	...	570 (23)	...	90
Titanium	...	...	Saturated with zirconyl nitrate	33-45	118 (244)	...	Resistant	...	90
Titanium	...	...	White fuming	Liquid or vapor	Room	...	Resistant	...	90
Titanium	...	...	White fuming	...	82 (180)	...	0.152 (6.08)	...	90

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	White fuming	...	122 (252)	...	0.13 (5.1) max	...	90
Titanium	...	...	White fuming	...	160 (320)	...	0.13 (5.1) max	...	90
Titanium, grade 1	R50250	...	...	25	Boiling	196 h	0.15 (6)	...	27
Titanium, grade 1	R50250	...	...	45	Boiling	196 h	0.39 (15)	...	27
Titanium, grade 1	R50250	...	...	70	Boiling	196 h	0.08 (3.1)	...	27
Titanium, grade 12	R53400	...	...	25	Boiling	196 h	0.18 (7)	...	27
Titanium, grade 12	R53400	...	...	45	Boiling	196 h	0.27 (11)	...	27
Titanium, grade 12	R53400	...	...	70	Boiling	196 h	0.06 (2.4)	...	27
Titanium, grade 2	R50400	...	...	50	79 (175)	48 h	.091 (3.6)	...	223
Titanium, grade 2	R50400	...	Plus 1000 ppm chloride, 100 ppm fluoride	50	79 (175)	48 h	1.115 (43.9)	...	223
Titanium, grade 2	R50400	...	Plus 20 ppm fluoride	50	79 (175)	48 h	.305 (12.0)	...	223
Titanium, grade 2	R50400	...	Plus 300 ppm chloride	50	79 (175)	48 h	0.117 (4.6)	...	223
Titanium, grade 2	R50400	...	Plus 300 ppm chloride, 20 ppm fluoride	50	79 (175)	48 h	.914 (36.0)	...	223
Titanium, grade 5	R56400	...	...	25	Boiling	196 h	0.67 (26)	...	27
Titanium, grade 5	R56400	...	...	45	Boiling	196 h	0.86 (34)	...	27
Titanium, grade 5	R56400	...	...	70	Boiling	196 h	0.02 (0.8)	...	27
Titanium, grade 7	R52400	...	...	25	Boiling	196 h	0.17 (6.7)	...	27
Titanium, grade 7	R52400	...	...	45	Boiling	196 h	0.38 (15)	...	27
Titanium, grade 7	R52400	...	...	70	Boiling	196 h	0.07 (2.8)	...	27
Titanium, grade 9	...	...	...	10	Boiling	...	0.08 (3.3)	...	91
Titanium, grade 9	...	...	...	20	Boiling	...	0.26 (11)	...	91
Titanium, grade 9	...	...	...	30	Boiling	...	0.49 (20)	...	91
Titanium, grade 9	...	...	...	40	Boiling	...	0.69 (28)	...	91
Titanium, grade 9	...	...	...	50	Boiling	...	0.45 (18)	...	91
Titanium, grade 9	...	...	...	60	Boiling	...	0.35 (14)	...	91
Titanium, grade 9	...	...	...	65	204 (399)	...	0.007 (0.3)	...	91
Titanium, grade 9	...	...	...	70	Boiling	...	0.13 (5.4)	...	91
Titanium, grade 9	...	...	...	10	Boiling	...	0.084 (3.30)	...	33
Titanium, grade 9	...	...	...	25	Boiling	196 h	0.18 (7)	...	27
Titanium, grade 9	...	...	...	30	Boiling	...	0.497 (19.5)	...	33
Titanium, grade 9	...	...	...	45	Boiling	196 h	0.54 (21)	...	27
Titanium, grade 9	...	...	...	70	Boiling	196 h	0.10 (4)	...	27
Transage 207	...	...	...	25	Boiling	196 h	8.0 (315)	...	27
Transage 207	...	...	...	45	Boiling	196 h	15.6 (614)	...	27
Transage 207	...	...	...	70	Boiling	196 h	0.95 (37.4)	...	27
Zirconium	R60701	...	...	Concentrated	19-26 (65-80)	36 d	Resistant	...	74
Zr702	R60702	...	...	10-70	Room to 260 (Room to 500)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	20	103 (215)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	70	121 (250)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	70-98	Room to Boiling	...	0.025 (1) max	Stress-corrosion cracking	15
Zr702	R60702	...	Plus 1% Cl	70	120 (248)	...	Resistant	...	15
Zr702	R60702	...	Plus 1% Fe	65	120 (248)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 1% Fe	65	204 (400)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 1% $FeCl_3$	70	120 (248)	...	Resistant	...	15
Zr702	R60702	...	Plus 1% seawater	70	120 (248)	...	Resistant	...	15
Zr704	R60704	...	...	20	103 (215)	...	0.025 (1) max	...	15
Zr704	R60704	...	...	70	121 (250)	...	0.025 (1) max	...	15
Zr705	R60705	...	...	20	103 (215)	...	0.025 (1) max	...	15
Zr705	R60705	...	...	70	121 (250)	...	0.025 (1) max	...	15
Stainless steels									
18Cr-2Ni-12Mn	S24100	...	Test conducted in three 48-h periods	20 wt%	93 (200)	48 h	0.375 (1.5)	...	47

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
20 Cb-3	N08020	...	...	60	Boiling	...	0.18 (7)	...	212
20 Cb-3	N08020	...	Plus 1% HF	20	52 (125)	...	1.43 (57)	...	212
20 Cb-3	N08020	...	Plus 1% HF	20	79 (175)	...	5.6 (225)	...	212
20 Cb-3	N08020	...	Plus 3% HF	20	52 (125)	...	3.5 (140)	...	212
20 Cb-3	N08020	...	Plus 3% HF	20	79 (175)	...	19 (762)	...	212
20 Cb-3	N08020	...	Plus 5% HF	20	52 (125)	...	6.2 (249)	...	212
20 Cb-3	N08020	...	Plus 5% HF	20	79 (175)	...	30 (1211)	...	212
20Cb-3	N08020	...	...	65	Boiling	...	0.20 (8)	...	219
20Cb-3	N08020	...	Five 48-h exposure	65	Boiling	...	0.14 (5.6)	...	217
20Cb-3	N08020	...	Plus 4% HF	20	60 (140)	...	9.3 (372)	...	217
301	S30100	...	...	7	20 (68)	...	Resistant	...	253
301	S30100	...	...	7	Boiling	...	Resistant	...	253
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
301	S30100	...	...	25	20 (68)	...	Resistant	...	253
301	S30100	...	...	25	Boiling	...	Resistant	...	253
301	S30100	...	...	37	20 (68)	...	Resistant	...	253
301	S30100	...	...	37	Boiling	...	Resistant	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Good	...	253
301	S30100	...	...	66	20 (68)	...	Resistant	...	253
301	S30100	...	...	66	Boiling	...	Good	...	253
301	S30100	...	...	99	20 (68)	...	Good	...	253
301	S30100	...	...	99	Boiling	...	Questionable	...	253
301	S30100	...	...	...	Boiling	...	Good	...	253
301	S30100	...	...	...	Boiling	...	Good	...	253
302	S30200	...	...	7	20 (68)	...	Resistant	...	253
302	S30200	...	...	7	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Resistant	...	253
302	S30200	...	...	37	20 (68)	...	Resistant	...	253
302	S30200	...	...	37	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Good	...	253
302	S30200	...	...	66	20 (68)	...	Resistant	...	253
302	S30200	...	...	66	Boiling	...	Good	...	253
302	S30200	...	...	99	20 (68)	...	Good	...	253
302	S30200	...	...	99	Boiling	...	Questionable	...	253
302	S30200	...	...	...	Boiling	...	Good	...	253
302	S30200	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	7	20 (68)	...	Resistant	...	253
303	S30300	...	...	7	20 (68)	...	Resistant	...	253
303	S30300	...	...	7	Boiling	...	Resistant	...	253
303	S30300	...	...	7	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Good	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	37	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	37	20 (68)	...	Resistant	...	253
303	S30300	...	...	37	Boiling	...	Good	...	253
303	S30300	...	...	37	Boiling	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Good	...	253
303	S30300	...	...	50	Boiling	...	Good	...	253
303	S30300	...	...	66	20 (68)	...	Resistant	...	253
303	S30300	...	...	66	20 (68)	...	Resistant	...	253
303	S30300	...	...	66	Boiling	...	Questionable	...	253
303	S30300	...	...	66	Boiling	...	Good	...	253
303	S30300	...	...	99	20 (68)	...	Good	...	253
303	S30300	...	...	99	20 (68)	...	Good	...	253
303	S30300	...	...	99	Boiling	...	Poor	...	253
303	S30300	...	...	99	Boiling	...	Questionable	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	10	Boiling	...	Resistant	...	121
304	S30400	...	...	20	21 (70)	...	Resistant	...	121
304	S30400	...	...	20	Boiling	...	Good	...	121
304	S30400	...	...	25	Boiling	...	0.06 (2.4)	...	120
304	S30400	...	...	40	21 (70)	...	Resistant	...	121
304	S30400	...	...	40	Boiling	...	Good	...	121
304	S30400	...	...	90	21 (70)	...	Resistant	...	121
304	S30400	...	...	100	21 (70)	...	Resistant	...	121
304	S30400	...	...	100	Boiling	...	Poor	...	121
304	S30400	...	...	65	122 (251)	2 d	0.13 (5.1)	...	214
304	S30400	...	...	65	122 (251)	6 d	0.26 (10.2)	...	214
304	S30400	...	...	65	Boiling	...	0.20 (8)	...	219
304	S30400	...	...	50	79 (175)	48 h	.015 (0.8)	...	223
304	S30400	...	...	7	20 (68)	...	Resistant	...	253
304	S30400	...	...	7	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Resistant	...	253
304	S30400	...	...	37	20 (68)	...	Resistant	...	253
304	S30400	...	...	37	Boiling	...	Resistant	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Good	...	253
304	S30400	...	...	66	20 (68)	...	Resistant	...	253
304	S30400	...	...	66	Boiling	...	Good	...	253
304	S30400	...	...	99	20 (68)	...	Good	...	253
304	S30400	...	...	99	Boiling	...	Questionable	...	253
304	S30400	...	...	...	Boiling	...	Good	...	253
304	S30400	...	...	...	Boiling	...	Good	...	253
304	S30400	...	No activation	40	Boiling	24 h	0.06 (2.4)	...	52
304	S30400	...	Plus 1000 ppm chloride, 100 ppm fluoride	50	79 (175)	48 h	.241 (9.5)	...	223
304	S30400	...	Plus 20 ppm fluoride	50	79 (175)	48 h	.079 (3.1)	...	223
304	S30400	...	Plus 300 ppm chloride	50	79 (175)	48 h	.025 (1.0)	...	223
304	S30400	...	Plus 300 ppm chloride, 20 ppm fluoride	50	79 (175)	48 h	.102 (4.0)	...	223

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Test conducted in three 48-h periods	20 wt%	93 (200)	48 h	0.027 (1.1)	...	47
304L	S30403	...	...	65	Boiling	...	0.24 (9.6)	...	136
304L	S30403	...	...	10	149 (300)	144 h	0.15 (6)	...	213
304L	S30403	...	...	20	149 (300)	144 h	0.55 (22)	...	213
304L	S30403	...	...	30	149 (300)	144 h	0.60 (24)	...	213
304L	S30403	...	...	7	20 (68)	...	Resistant	...	253
304L	S30403	...	...	7	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Resistant	...	253
304L	S30403	...	...	37	20 (68)	...	Resistant	...	253
304L	S30403	...	...	37	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Good	...	253
304L	S30403	...	...	66	20 (68)	...	Resistant	...	253
304L	S30403	...	...	66	Boiling	...	Good	...	253
304L	S30403	...	...	99	20 (68)	...	Good	...	253
304L	S30403	...	...	99	Boiling	...	Questionable	...	253
304L	S30403	...	...	...	Boiling	...	Good	...	253
304L	S30403	...	...	...	Boiling	...	Good	...	253
304L	S30403	...	Five 48-h exposure	65	Boiling	...	0.17 (6.8)	...	217
304LN	S30453	...	...	7	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	7	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Resistant	...	253
304LN	S30453	...	...	37	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	37	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Good	...	253
304LN	S30453	...	...	66	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	66	Boiling	...	Good	...	253
304LN	S30453	...	...	99	20 (68)	...	Good	...	253
304LN	S30453	...	...	99	Boiling	...	Questionable	...	253
304LN	S30453	...	...	...	Boiling	...	Good	...	253
304LN	S30453	...	...	...	Boiling	...	Good	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	10	Boiling	...	Resistant	...	121
316	S31600	...	...	20	21 (70)	...	Resistant	...	121
316	S31600	...	...	20	Boiling	...	Good	...	121
316	S31600	...	...	40	21 (70)	...	Resistant	...	121
316	S31600	...	...	40	Boiling	...	Good	...	121
316	S31600	...	...	90	21 (70)	...	Resistant	...	121
316	S31600	...	...	100	21 (70)	...	Resistant	...	121
316	S31600	...	...	100	Boiling	...	Poor	...	121
316	S31600	...	...	65	122 (251)	2 d	0.11 (4.5)	...	214
316	S31600	...	...	65	122 (251)	6 d	0.37 (14.8)	...	214
316	S31600	...	...	65	Boiling	...	.28 (11)	...	219
316	S31600	...	...	7	20 (68)	...	Resistant	...	253
316	S31600	...	...	7	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Resistant	...	253
316	S31600	...	...	37	20 (68)	...	Resistant	...	253
316	S31600	...	...	37	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Good	...	253
316	S31600	...	...	66	20 (68)	...	Resistant	...	253
316	S31600	...	...	66	Boiling	...	Good	...	253
316	S31600	...	...	99	20 (68)	...	Questionable	...	253
316	S31600	...	...	99	Boiling	...	Questionable	...	253
316	S31600	...	...	...	Boiling	...	Good	...	253
316	S31600	...	...	...	Boiling	...	Good	...	253
316	S31600	...	No activation	40	Boiling	24 h	0.055 (2.2)	...	52
316F	S31620	...	...	7	20 (68)	...	Resistant	...	253
316F	S31620	...	...	7	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Resistant	...	253
316F	S31620	...	...	37	20 (68)	...	Resistant	...	253
316F	S31620	...	...	37	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Good	...	253
316F	S31620	...	...	66	20 (68)	...	Resistant	...	253
316F	S31620	...	...	66	Boiling	...	Good	...	253
316F	S31620	...	...	99	20 (68)	...	Good	...	253
316F	S31620	...	...	99	Boiling	...	Questionable	...	253
316F	S31620	...	...	...	Boiling	...	Good	...	253
316F	S31620	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	...	60	Boiling	...	0.40 (16)	...	212
316L	S31603	...	...	7	20 (68)	...	Resistant	...	253
316L	S31603	...	...	7	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Resistant	...	253
316L	S31603	...	...	37	20 (68)	...	Resistant	...	253
316L	S31603	...	...	37	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Good	...	253
316L	S31603	...	...	66	20 (68)	...	Resistant	...	253
316L	S31603	...	...	66	Boiling	...	Good	...	253
316L	S31603	...	...	99	20 (68)	...	Questionable	...	253
316L	S31603	...	...	99	Boiling	...	Questionable	...	253
316L	S31603	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	Five 48-h exposure	65	Boiling	...	0.30 (12.0)	...	217
316L	S31603	...	Plus 1% HF	20	52 (125)	...	9.0 (360)	...	212
316L	S31603	...	Plus 1% HF	20	79 (175)	...	...	...	212
316L	S31603	...	Plus 3% HF	20	52 (125)	...	7.6 (303)	...	212
316L	S31603	...	Plus 3% HF	20	79 (175)	...	...	...	212
316L	S31603	...	Plus 5% HF	20	52 (125)	...	29 (1154)	...	212
316L	S31603	...	Plus 5% HF	20	79 (175)	...	...	...	212
316LN	S31653	...	...	7	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	7	Boiling	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Resistant	...	253
316LN	S31653	...	...	37	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	37	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Good	...	253
316LN	S31653	...	...	66	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	66	Boiling	...	Good	...	253
316LN	S31653	...	...	99	20 (68)	...	Questionable	...	253
316LN	S31653	...	...	99	Boiling	...	Questionable	...	253
316LN	S31653	...	...	...	Boiling	...	Good	...	253
316LN	S31653	...	...	...	Boiling	...	Good	...	253
316Ti	S31635	...	...	7	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	7	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	37	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	37	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Good	...	253
316Ti	S31635	...	...	66	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	66	Boiling	...	Good	...	253
316Ti	S31635	...	...	99	20 (68)	...	Questionable	...	253
316Ti	S31635	...	...	99	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	...	Boiling	...	Good	...	253
316Ti	S31635	...	...	...	Boiling	...	Good	...	253
317L	S31703	...	...	25	Boiling	48 h	0.05 (2) max	...	97
317L	S31703	...	...	65	Boiling	...	0.53 (21)	...	219
317L	S31703	...	...	7	20 (68)	...	Resistant	...	253
317L	S31703	...	...	7	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Resistant	...	253
317L	S31703	...	...	37	20 (68)	...	Resistant	...	253
317L	S31703	...	...	37	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Good	...	253
317L	S31703	...	...	66	20 (68)	...	Resistant	...	253
317L	S31703	...	...	66	Boiling	...	Good	...	253
317L	S31703	...	...	99	20 (68)	...	Questionable	...	253
317L	S31703	...	...	99	Boiling	...	Questionable	...	253
317L	S31703	...	...	...	Boiling	...	Good	...	253
317L	S31703	...	...	...	Boiling	...	Good	...	253
317LN	S31725	...	...	7	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	7	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Resistant	...	253
317LN	S31725	...	...	37	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	37	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Good	...	253
317LN	S31725	...	...	66	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	66	Boiling	...	Good	...	253
317LN	S31725	...	...	99	20 (68)	...	Questionable	...	253
317LN	S31725	...	...	99	Boiling	...	Questionable	...	253
317LN	S31725	...	...	...	Boiling	...	Good	...	253
317LN	S31725	...	...	...	Boiling	...	Good	...	253
321	S32100	...	...	7	20 (68)	...	Resistant	...	253
321	S32100	...	...	7	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Resistant	...	253
321	S32100	...	...	37	20 (68)	...	Resistant	...	253
321	S32100	...	...	37	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Good	...	253
321	S32100	...	...	66	20 (68)	...	Resistant	...	253
321	S32100	...	...	66	Boiling	...	Good	...	253
321	S32100	...	...	99	20 (68)	...	Good	...	253
321	S32100	...	...	99	Boiling	...	Questionable	...	253
321	S32100	...	...	...	Boiling	...	Good	...	253
321	S32100	...	...	...	Boiling	...	Good	...	253
329	S32900	...	...	10	149 (300)	144 h	0.05 (2)	...	213
329	S32900	...	...	20	149 (300)	144 h	0.38 (15)	...	213
329	S32900	...	...	30	149 (300)	144 h	0.40 (16)	...	213
329	S32900	...	...	7	20 (68)	...	Resistant	...	253
329	S32900	...	...	7	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Resistant	...	253
329	S32900	...	...	37	20 (68)	...	Resistant	...	253
329	S32900	...	...	37	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Good	...	253
329	S32900	...	...	66	20 (68)	...	Resistant	...	253
329	S32900	...	...	66	Boiling	...	Good	...	253
329	S32900	...	...	99	20 (68)	...	Questionable	...	253
329	S32900	...	...	99	Boiling	...	Questionable	...	253
329	S32900	...	...	...	Boiling	...	Good	...	253
329	S32900	...	...	...	Boiling	...	Good	...	253
347	S34700	...	...	65	Boiling	...	0.27 (10.8)	...	136
347	S34700	...	...	7	20 (68)	...	Resistant	...	253
347	S34700	...	...	7	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Resistant	...	253
347	S34700	...	...	37	20 (68)	...	Resistant	...	253
347	S34700	...	...	37	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	...	66	20 (68)	...	Resistant	...	253
347	S34700	...	...	66	Boiling	...	Good	...	253
347	S34700	...	...	99	20 (68)	...	Good	...	253
347	S34700	...	...	99	Boiling	...	Questionable	...	253
347	S34700	...	...	...	Boiling	...	Good	...	253
347	S34700	...	...	...	Boiling	...	Good	...	253
347	S34700	...	Liquid	85.1	22 (77)	...	0.003 (0.1)	...	137
347	S34700	...	Liquid	90.1	22 (77)	...	0.003 (0.1)	...	137
347	S34700	...	Liquid	92.6	22 (77)	...	0.003 (0.1)	...	137
347	S34700	...	Liquid	94.2	22 (77)	...	0.06 (2.3)	...	137
347	S34700	...	Liquid	96.3	22 (77)	...	0.40 (16)	...	137
347	S34700	...	Liquid	98.5	22 (77)	...	1.5 (61)	...	137
347	S34700	...	Vapor	85.1	22 (77)	...	0.003 (0.1)	...	137
347	S34700	...	Vapor	90.1	22 (77)	...	0.18 (7)	...	137
347	S34700	...	Vapor	92.6	22 (77)	...	0.71 (28)	...	137
347	S34700	...	Vapor	94.2	22 (77)	...	0.76 (30)	...	137
347	S34700	...	Vapor	96.3	22 (77)	...	0.97 (38)	...	137
347	S34700	...	Vapor	98.5	22 (77)	...	1.2 (47)	...	137
403	S40300	...	...	7	20 (68)	...	Resistant	...	253
403	S40300	...	...	7	Boiling	...	Good	...	253
403	S40300	...	...	10	20 (68)	...	Resistant	...	253
403	S40300	...	...	10	Boiling	...	Good	...	253
403	S40300	...	...	25	20 (68)	...	Resistant	...	253
403	S40300	...	...	25	Boiling	...	Questionable	...	253
403	S40300	...	...	37	20 (68)	...	Resistant	...	253
403	S40300	...	...	37	Boiling	...	Questionable	...	253
403	S40300	...	...	50	20 (68)	...	Resistant	...	253
403	S40300	...	...	50	Boiling	...	Questionable	...	253
403	S40300	...	...	66	20 (68)	...	Resistant	...	253
403	S40300	...	...	66	Boiling	...	Poor	...	253
403	S40300	...	...	99	20 (68)	...	Questionable	...	253
403	S40300	...	...	99	Boiling	...	Poor	...	253
405	S40500	...	...	7	20 (68)	...	Resistant	...	253
405	S40500	...	...	7	Boiling	...	Good	...	253
405	S40500	...	...	10	20 (68)	...	Resistant	...	253
405	S40500	...	...	10	Boiling	...	Good	...	253
405	S40500	...	...	25	20 (68)	...	Resistant	...	253
405	S40500	...	...	25	Boiling	...	Questionable	...	253
405	S40500	...	...	37	20 (68)	...	Resistant	...	253
405	S40500	...	...	37	Boiling	...	Questionable	...	253
405	S40500	...	...	50	20 (68)	...	Resistant	...	253
405	S40500	...	...	50	Boiling	...	Questionable	...	253
405	S40500	...	...	66	20 (68)	...	Resistant	...	253
405	S40500	...	...	66	Boiling	...	Poor	...	253
405	S40500	...	...	99	20 (68)	...	Questionable	...	253
405	S40500	...	...	99	Boiling	...	Poor	...	253
409	S40900	...	...	7	20 (68)	...	Resistant	...	253
409	S40900	...	...	7	Boiling	...	Good	...	253
409	S40900	...	...	10	20 (68)	...	Resistant	...	253
409	S40900	...	...	10	Boiling	...	Good	...	253
409	S40900	...	...	25	20 (68)	...	Resistant	...	253
409	S40900	...	...	25	Boiling	...	Questionable	...	253
409	S40900	...	...	37	20 (68)	...	Resistant	...	253
409	S40900	...	...	37	Boiling	...	Questionable	...	253
409	S40900	...	...	50	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	50	Boiling	...	Questionable	...	253
409	S40900	...	...	66	20 (68)	...	Resistant	...	253
409	S40900	...	...	66	Boiling	...	Poor	...	253
409	S40900	...	...	99	20 (68)	...	Questionable	...	253
409	S40900	...	...	99	Boiling	...	Poor	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	10	Boiling	...	Poor	...	121
410	S41000	...	...	20	21 (70)	...	Good	...	121
410	S41000	...	...	20	Boiling	...	Poor	...	121
410	S41000	...	...	40	21 (70)	...	Good	...	121
410	S41000	...	...	40	Boiling	...	Poor	...	121
410	S41000	...	...	90	21 (70)	...	Poor	...	121
410	S41000	...	...	100	21 (70)	...	Poor	...	121
410	S41000	...	...	100	Boiling	...	Poor	...	121
410	S41000	...	...	7	20 (68)	...	Resistant	...	253
410	S41000	...	...	7	Boiling	...	Good	...	253
410	S41000	...	...	10	20 (68)	...	Resistant	...	253
410	S41000	...	...	10	Boiling	...	Good	...	253
410	S41000	...	...	25	20 (68)	...	Resistant	...	253
410	S41000	...	...	25	Boiling	...	Questionable	...	253
410	S41000	...	...	37	20 (68)	...	Resistant	...	253
410	S41000	...	...	37	Boiling	...	Questionable	...	253
410	S41000	...	...	50	20 (68)	...	Resistant	...	253
410	S41000	...	...	50	Boiling	...	Questionable	...	253
410	S41000	...	...	66	20 (68)	...	Resistant	...	253
410	S41000	...	...	66	Boiling	...	Poor	...	253
410	S41000	...	...	99	20 (68)	...	Questionable	...	253
410	S41000	...	...	99	Boiling	...	Poor	...	253
410	S41000	...	Plus 2% HCl	Concentrated	Room	...	Poor	...	121
416	S41600	...	...	7	20 (68)	...	Resistant	...	253
416	S41600	...	...	7	Boiling	...	Good	...	253
416	S41600	...	...	10	20 (68)	...	Resistant	...	253
416	S41600	...	...	10	Boiling	...	Good	...	253
416	S41600	...	...	25	20 (68)	...	Resistant	...	253
416	S41600	...	...	25	Boiling	...	Questionable	...	253
416	S41600	...	...	37	20 (68)	...	Resistant	...	253
416	S41600	...	...	37	Boiling	...	Questionable	...	253
416	S41600	...	...	50	20 (68)	...	Resistant	...	253
416	S41600	...	...	50	Boiling	...	Questionable	...	253
416	S41600	...	...	66	20 (68)	...	Resistant	...	253
416	S41600	...	...	66	Boiling	...	Poor	...	253
416	S41600	...	...	99	20 (68)	...	Questionable	...	253
416	S41600	...	...	99	Boiling	...	Poor	...	253
420	S42000	...	...	7	20 (68)	...	Resistant	...	253
420	S42000	...	...	7	Boiling	...	Good	...	253
420	S42000	...	...	10	20 (68)	...	Resistant	...	253
420	S42000	...	...	10	Boiling	...	Good	...	253
420	S42000	...	...	25	20 (68)	...	Resistant	...	253
420	S42000	...	...	25	Boiling	...	Questionable	...	253
420	S42000	...	...	37	20 (68)	...	Resistant	...	253
420	S42000	...	...	37	Boiling	...	Questionable	...	253
420	S42000	...	...	50	20 (68)	...	Resistant	...	253
420	S42000	...	...	50	Boiling	...	Questionable	...	253
420	S42000	...	...	66	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	66	Boiling	...	Poor	...	253
420	S42000	...	...	99	20 (68)	...	Questionable	...	253
420	S42000	...	...	99	Boiling	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	Boiling	...	Good	...	121
430	S43000	...	...	20	21 (70)	...	Good	...	121
430	S43000	...	...	20	Boiling	...	Good	...	121
430	S43000	...	...	40	21 (70)	...	Good	...	121
430	S43000	...	...	40	Boiling	...	Good	...	121
430	S43000	...	...	65	Boiling	...	0.91 (36.4)	...	136
430	S43000	...	...	90	21 (70)	...	Good	...	121
430	S43000	...	...	100	21 (70)	...	Questionable	...	121
430	S43000	...	...	100	Boiling	...	Poor	...	121
430	S43000	...	...	10	149 (300)	144 h	0.40 (16)	...	213
430	S43000	...	...	20	149 (300)	144 h	1.15 (46)	...	213
430	S43000	...	...	30	149 (300)	144 h	0.95 (38)	...	213
430	S43000	...	...	7	20 (68)	...	Resistant	...	253
430	S43000	...	...	7	Boiling	...	Resistant	...	253
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Good	...	253
430	S43000	...	...	25	20 (68)	...	Resistant	...	253
430	S43000	...	...	25	Boiling	...	Good	...	253
430	S43000	...	...	37	20 (68)	...	Resistant	...	253
430	S43000	...	...	37	Boiling	...	Good	...	253
430	S43000	...	...	50	20 (68)	...	Resistant	...	253
430	S43000	...	...	50	Boiling	...	Good	...	253
430	S43000	...	...	66	20 (68)	...	Resistant	...	253
430	S43000	...	...	66	Boiling	...	Questionable	...	253
430	S43000	...	...	99	20 (68)	...	Good	...	253
430	S43000	...	...	99	Boiling	...	Poor	...	253
430	S43000	...	Liquid	85.1	22 (77)	...	0.01 (0.4)	...	137
430	S43000	...	Liquid	90.1	22 (77)	...	0.015 (0.6)	...	137
430	S43000	...	Liquid	92.6	22 (77)	...	0.03 (1.1)	...	137
430	S43000	...	Liquid	94.2	22 (77)	...	0.12 (4.6)	...	137
430	S43000	...	Liquid	96.3	22 (77)	...	0.50 (20)	...	137
430	S43000	...	Liquid	98.5	22 (77)	...	1.7 (67)	...	137
430	S43000	...	Vapor	85.1	22 (77)	...	0.003 (0.1)	...	137
430	S43000	...	Vapor	90.1	22 (77)	...	0.7 (27)	...	137
430	S43000	...	Vapor	92.6	22 (77)	...	0.69 (27)	...	137
430	S43000	...	Vapor	94.2	22 (77)	...	0.74 (29)	...	137
430	S43000	...	Vapor	96.3	22 (77)	...	1.1 (42)	...	137
430	S43000	...	Vapor	98.5	22 (77)	...	1.3 (51)	...	137
434	S43400	...	...	7	20 (68)	...	Resistant	...	253
434	S43400	...	...	7	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	25	20 (68)	...	Resistant	...	253
434	S43400	...	...	25	Boiling	...	Resistant	...	253
434	S43400	...	...	37	20 (68)	...	Resistant	...	253
434	S43400	...	...	37	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Good	...	253
434	S43400	...	...	66	20 (68)	...	Resistant	...	253
434	S43400	...	...	66	Boiling	...	Questionable	...	253

(Continued)

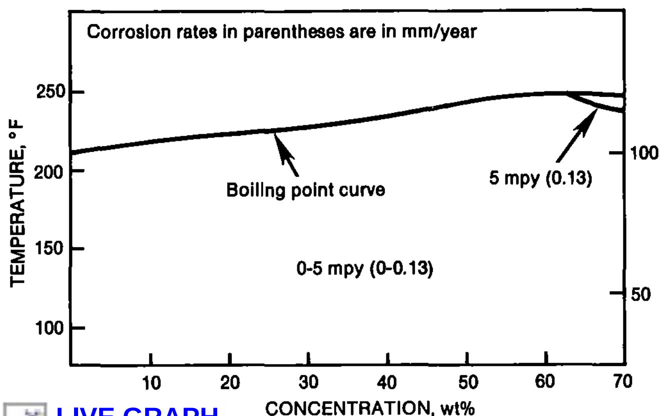
Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	99	20 (68)	...	Good	...	253
434	S43400	...	...	99	Boiling	...	Poor	...	253
444	S44400	...	No activation	40	Boiling	24 h	0.06 (2.3)	...	52
7-Mo	S32900	...	...	65	Boiling	...	0.18 (7.2)	...	136
ACI CF-8M	J92900	...	...	65	Boiling	6 d	0.40 (15.8)	...	214
ACI CF-8M	J92900	...	...	10	Boiling	4 d	0.03 (1) max	...	214
ACI CF-8M	J92900	...	...	65	90 (194)	4 d	0.10 (3.8)	...	214
ACI CF-8M	J92900	...	...	65	110 (230)	4 d	0.26 (10.4)	...	214
AL 2205	S31803	...	...	65	Boiling	...	.53 (21)	...	219
AL 29-4-2	S44800	...	...	50	79 (175)	48 h	.003 (0.1)	...	223
AL 29-4-2	S44800	...	Plus 1000 ppm chloride, 100 ppm fluoride	50	79 (175)	48 h	.063 (2.5)	...	223
AL 29-4-2	S44800	...	Plus 20 ppm fluoride	50	79 (175)	48 h	.018 (0.7)	...	223
AL 29-4-2	S44800	...	Plus 300 ppm chloride	50	79 (175)	48 h	.005 (0.2)	...	223
AL 29-4-2	S44800	...	Plus 300 ppm chloride, 20 ppm fluoride	50	79 (175)	48 h	.028 (1.1)	...	223
AL 29-4C	S44735	...	...	10	149 (300)	...	0.0025 (0.1)	...	80
AL 29-4C	S44735	...	...	20	149 (300)	...	0.05 (2.2)	...	80
AL 29-4C	S44735	...	...	30	149 (300)	...	0.102 (4.1)	...	80
Alloy 904L	N08904	...	...	60	Boiling	...	0.23 (9)	...	212
Alloy 904L	N08904	...	Five 48-h exposure	65	Boiling	...	0.45 (18.0)	...	217
Alloy 904L	N08904	...	Plus 1% HF	20	52 (125)	...	0.53 (21)	...	212
Alloy 904L	N08904	...	Plus 1% HF	20	79 (175)	...	2.33 (93)	...	212
Alloy 904L	N08904	...	Plus 3% HF	20	52 (125)	...	1.25 (50)	...	212
Alloy 904L	N08904	...	Plus 3% HF	20	79 (175)	...	7.1 (284)	...	212
Alloy 904L	N08904	...	Plus 4% HF	20	60 (140)	...	5.6 (224)	...	217
Alloy 904L	N08904	...	Plus 5% HF	20	52 (125)	...	2.5 (100)	...	212
Alloy 904L	N08904	...	Plus 5% HF	20	79 (175)	...	9.9 (397)	...	212
AM-363	S36300	...	...	...	Room	...	Good	...	120
CF-8	J92600	...	...	65	Boiling	6 d	0.45 (17.8)	...	214
CF-8	J92600	...	...	10	Boiling	4 d	0.03 (1) max	...	214
CF-8	J92600	...	...	65	90 (194)	4 d	0.08 (3.3)	...	214
CF-8	J92600	...	...	65	110 (230)	4 d	0.24 (9.7)	...	214
E-Brite	S44627	...	...	50	79 (175)	48 h	.005 (0.2)	...	223
E-Brite	S44627	...	Plus 1000 ppm chloride, 100 ppm fluoride	50	79 (175)	48 h	.089 (3.5)	...	223
E-Brite	S44627	...	Plus 20 ppm fluoride	50	79 (175)	48 h	.025 (0.1)	...	223
E-Brite	S44627	...	Plus 300 ppm chloride	50	79 (175)	48 h	.010 (0.4)	...	223
E-Brite	S44627	...	Plus 300 ppm chloride, 20 ppm fluoride	50	79 (175)	48 h	.041 (1.6)	...	223
F51	S31803	...	...	7	20 (68)	...	Resistant	...	253
F51	S31803	...	...	7	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253
F51	S31803	...	...	25	Boiling	...	Resistant	...	253
F51	S31803	...	...	37	20 (68)	...	Resistant	...	253
F51	S31803	...	...	37	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Good	...	253
F51	S31803	...	...	66	20 (68)	...	Resistant	...	253
F51	S31803	...	...	66	Boiling	...	Good	...	253
F51	S31803	...	...	99	20 (68)	...	Questionable	...	253
F51	S31803	...	...	99	Boiling	...	Questionable	...	253
F51	S31803	...	...	...	Boiling	...	Good	...	253
F51	S31803	...	...	...	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Fe-47Cr (ferrite)	...	...	Oxidizing	65	Boiling	...	0.003 (0.1)	...	58
Fe-47Cr (sigma)	...	...	Oxidizing	65	Boiling	...	0.10 (3.9)	...	58
Ferralium 225	S32550	...	...	65	Boiling	...	.13 (5)	...	219
Jessop JS700	N08700	...	...	25	Boiling	48 h	0.05 (2) max	...	97
Jessop JS700	N08700	...	Huey test	65	Boiling	48 h	0.5 (20) max	...	97
Jessop JS700	N08700	...	Plus 3% HF	5	68 (155)	48 h	0.05 (2) max	...	97



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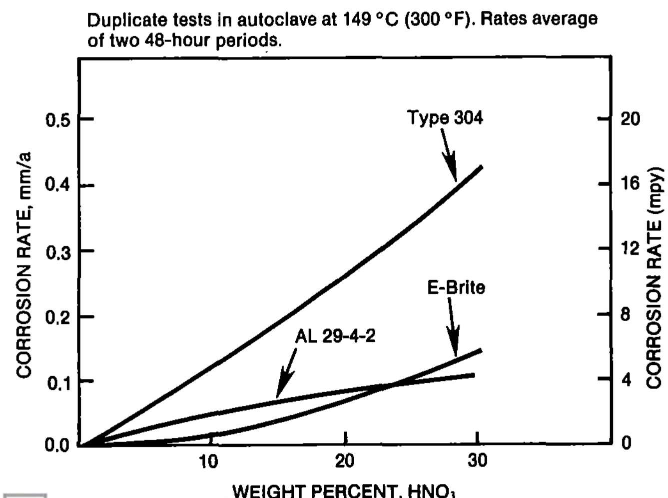
Stainless steel. Resistance to nitric acid of Ferralium Alloy 255. All test specimens were solution heat-treated and in the unwelded condition. Source: Haynes International, 1986.



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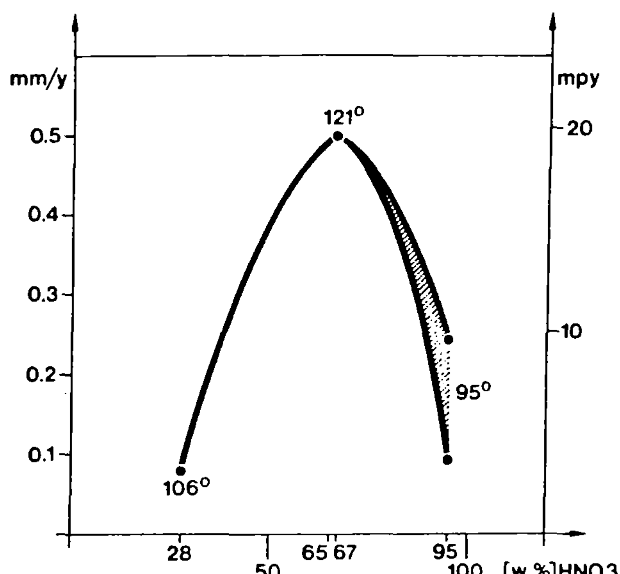
Stainless steel. Corrosion of AL 29-4-2 and other alloys in nitric acid at 149 °C (300 °F). Source: Allegheny Ludlum Corporation, 1982.



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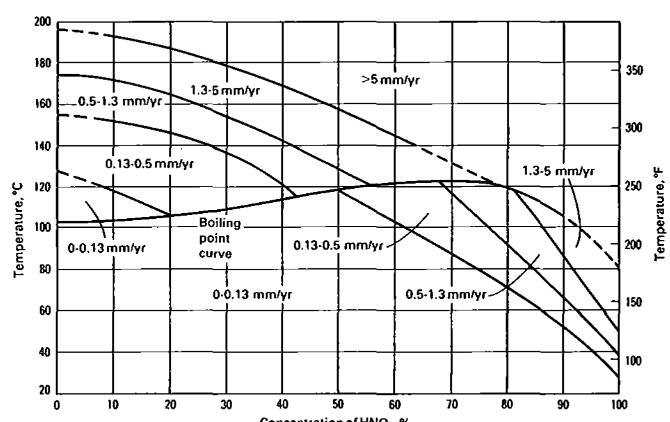
Stainless steel. Resistance of alloy 1815 (18Cr-15Ni-4Si) LCSi in nitric acid. Temperature in degrees Celsius. Source: R.R. Kirchheiner, F. Hofmann, *et al.*, "A Silicon-Alloyed Stainless Steel for Highly Oxidizing Conditions," *Materials Performance*, Vol 26, Jan 1987, 55.



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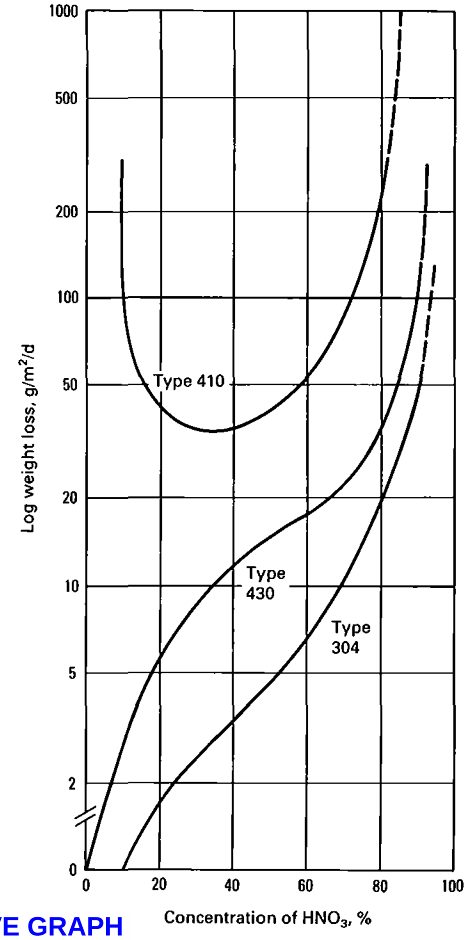
Stainless steel. Isocorrosion diagram for annealed type 304 stainless steel in nitric acid. Source: Chemical Processing Industry.



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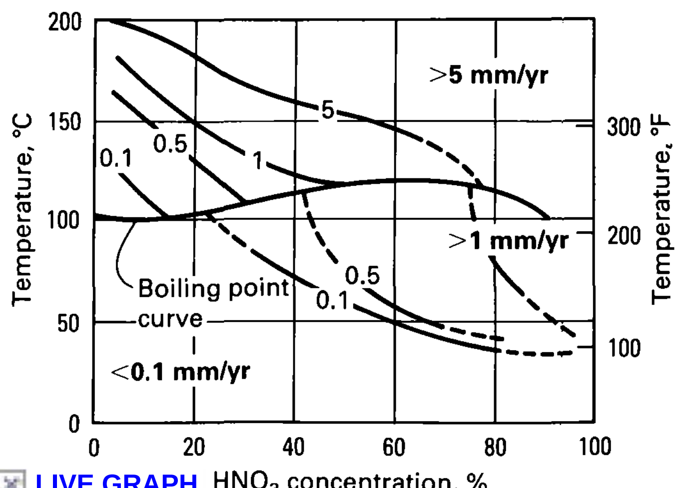
Stainless steel. Corrosion rates of various stainless steels in boiling nitric acid. Source: J.E. Tromen, in *Corrosion: Metal/Environment Reactions*, Vol 1, L.C. Shreir, Ed., Newness-Butterworths, 1976, 352.



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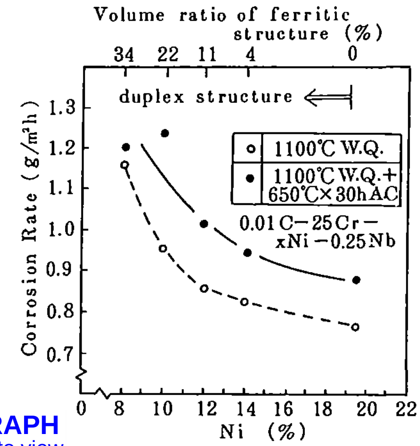
Stainless steel castings. Isocorrosion diagram for ACI CB-30 in nitric acid. Castings were annealed at 790 °C (1450 °F), furnace cooled to 540 °C (1000 °F), and then air cooled to room temperature. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 578.



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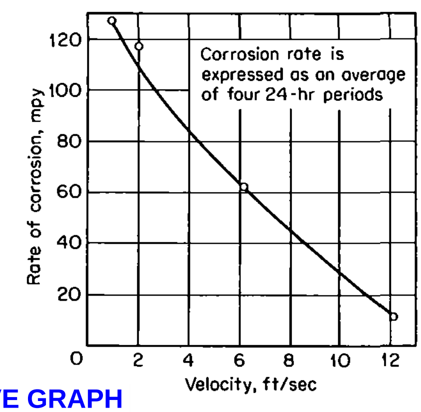
Stainless steel. Effect of nickel concentration on the corrosion of 25Cr steel in the boiling solution of 8*N* HNO_3 + 0.2 g/L Cr^{6+} ions. Source: H. Kajimura, H. Morikawa, *et al.*, Effect of Alloying Elements on the Corrosion Resistance of Stainless Steels in Nitric Acid, *Corrosion Resistance of Stainless Steels in Nitric Acid—Transactions of the Iron and Steel Institute of Japan*, *25*, B-131, 1985.



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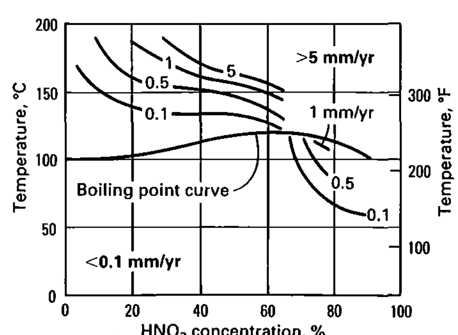
Stainless steel. Erosion corrosion of type 347 stainless steel by white fuming nitric acid at 108 °F. Source: M.G. Fontana, N.D. Green, *Corrosion Engineering*, McGraw-Hill, New York, 1967, 78.



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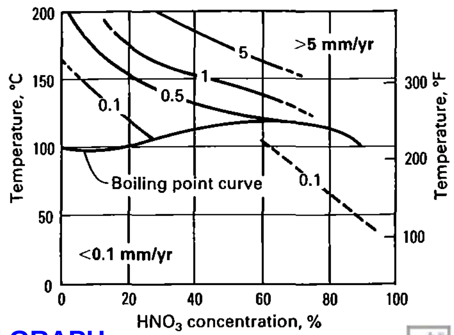
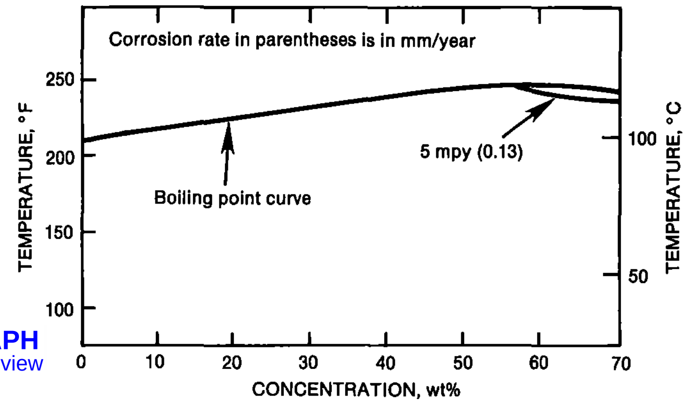
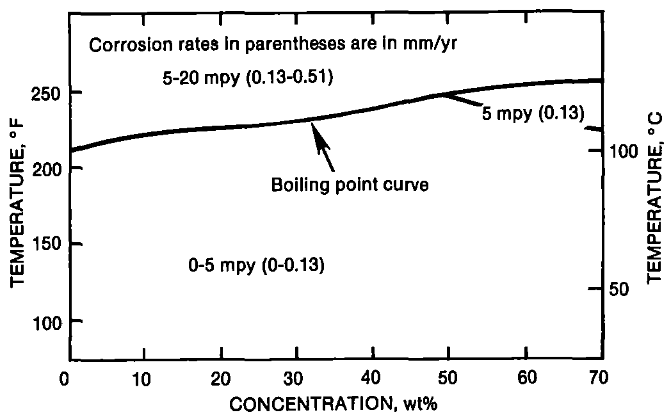
Stainless steel castings. Isocorrosion diagram for ACI CD-4MCu in nitric acid. The material was solution treated at 1120 °C (2050 °F) and water quenched. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 579.



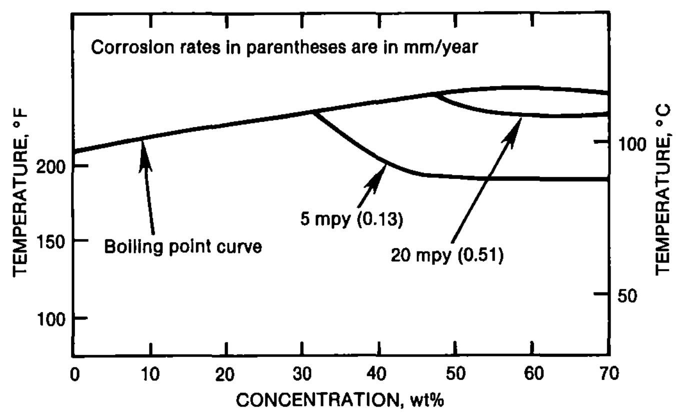
Stainless steel castings. Isocorrosion diagram for solution-treated quenched and sensitized ACI CF-3 in nitric acid. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 579.



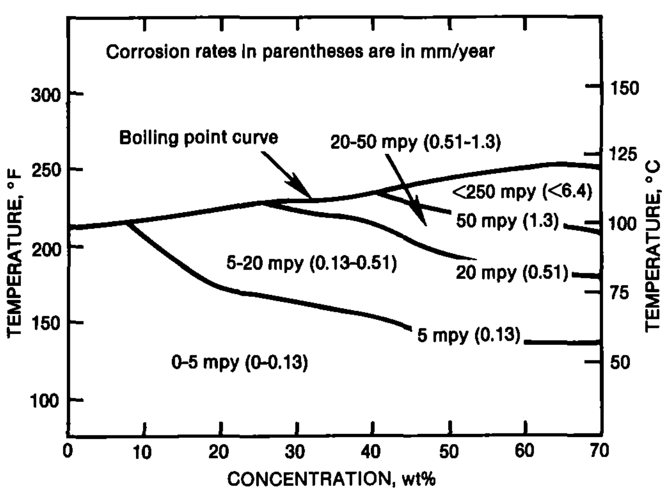
Hastelloy G-30. Resistance to nitric acid. All test specimens were heat treated at 1177 °C (2150 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.



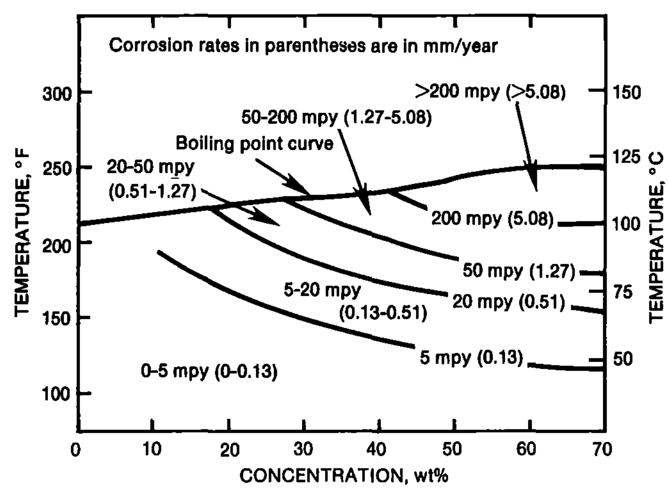
Hastelloy G-3. Resistance to nitric acid. All test specimens were solution heat-treated and in the unwelded condition. Source: Haynes International, 1984.



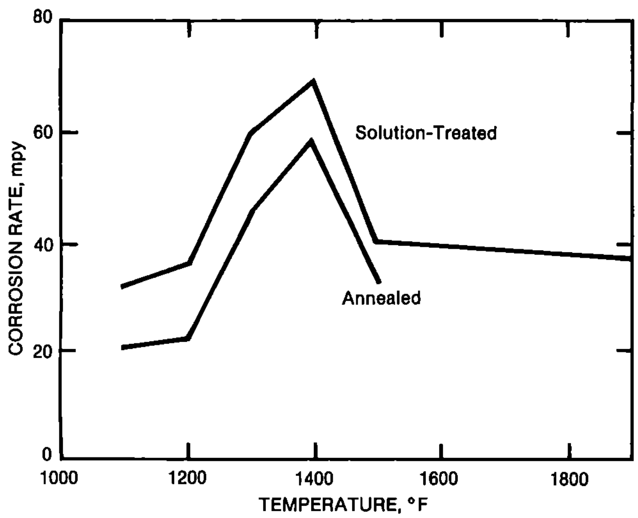
Hastelloy C-22. Resistance to nitric acid. All test specimens were solution heat-treated and in the unwelded condition. Source: Haynes International, 1984.



Hastelloy C-4. Resistance to nitric acid of Hastelloy C-4. All test specimens were solution heat-treated at 1066 °C (1950 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1983.



Hastelloy C-276. Resistance to nitric acid. All test specimens were heat-treated at 1121 °C (2050 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.



Inconel 625. Effect of sensitizing heat treatment (1 h at temperature) on corrosion of Inconel 625 in boiling 65% nitric acid (Huey test, average of five periods). Source: Inco Alloys International, 1985.

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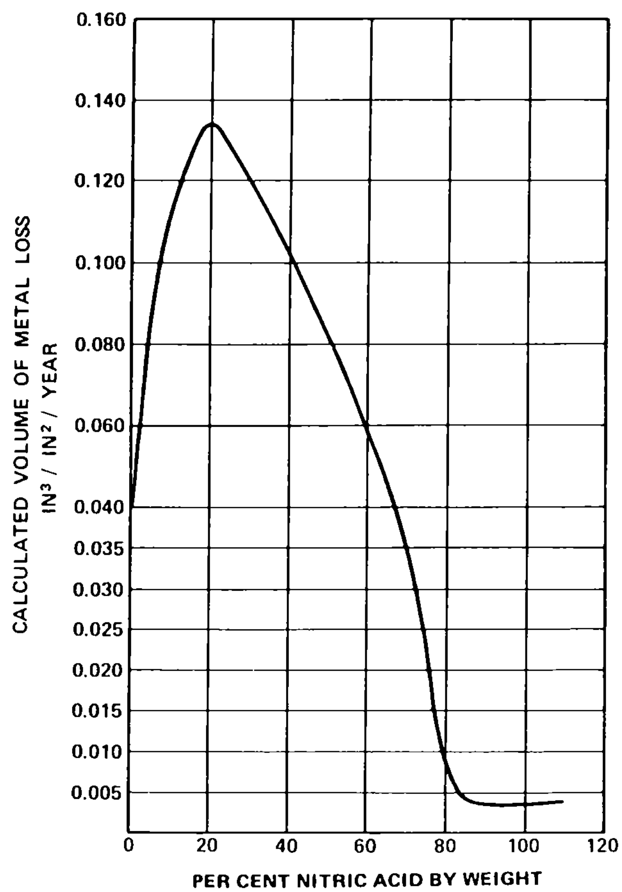
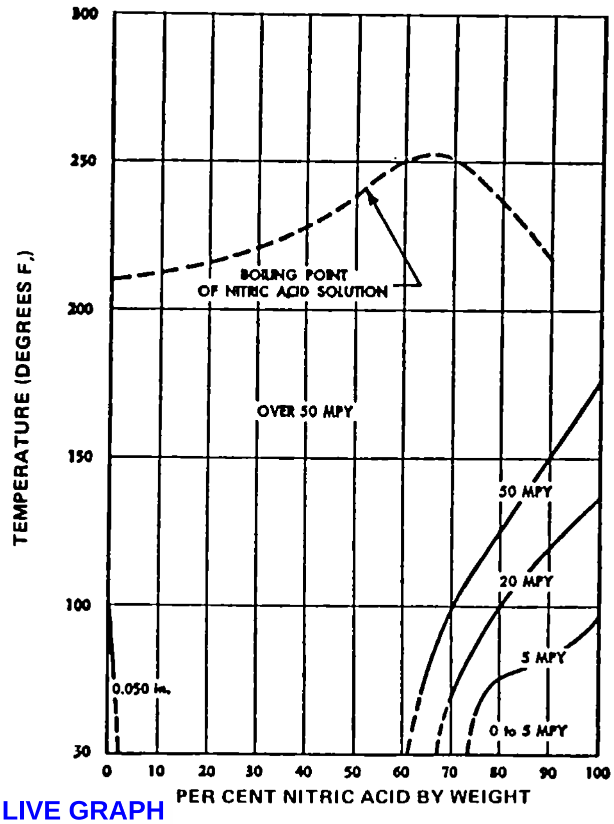


Aluminum. The resistance of alloy 1100 in nitric acid; results of 90-day tests at room temperature. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984.



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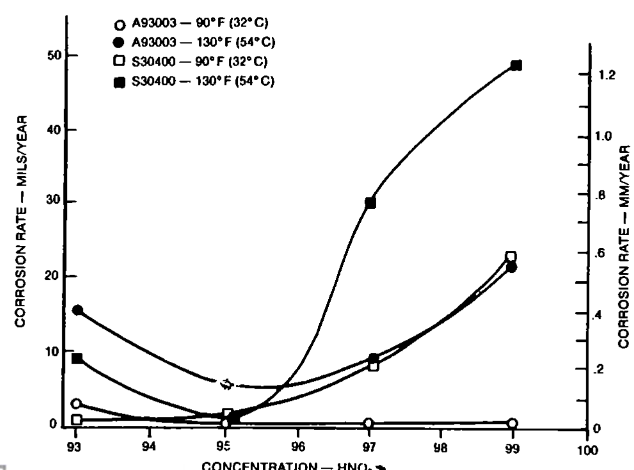
Aluminum. Corrosion rates of alloy 1100 in nitric acid, showing influence of concentration and temperature. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984.



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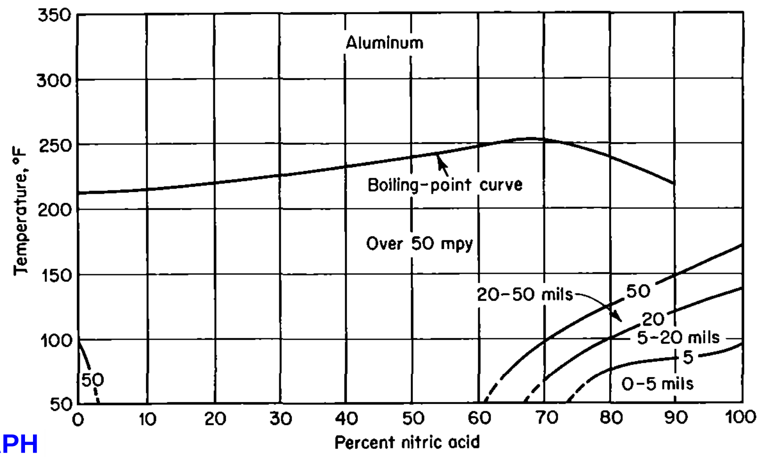
Aluminum. Corrosion rates of aluminum A93003 and stainless steel S30400 in concentrated nitric acid. Source: R.D. Crooks, "Materials of Construction for Nitric Acid," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986, 259.



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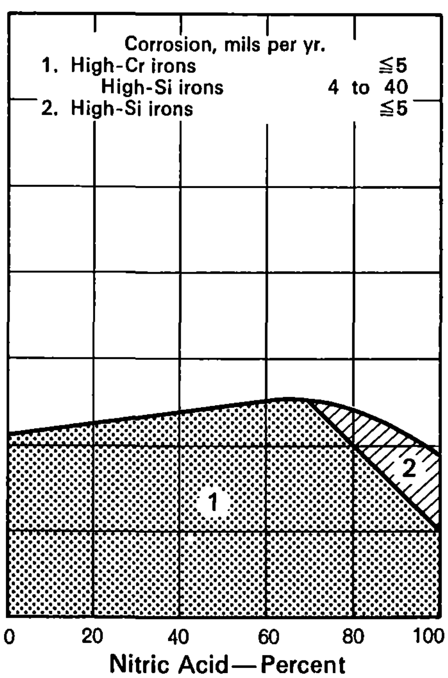
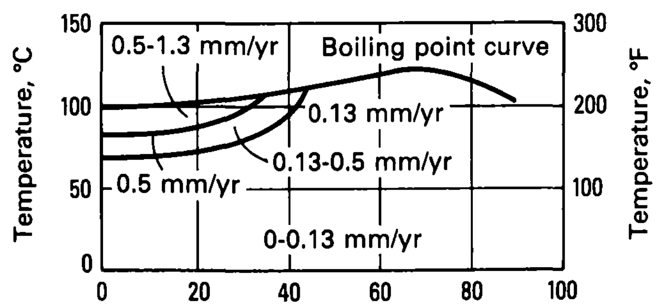
Aluminum. Corrosion of aluminum by nitric acid as a function of concentration and temperature. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984.



Cast iron. Useful life of plain and high-alloy iron castings in nitric acid. Source: "Physical and Corrosion Properties," in *Source Book on Ductile Iron*, A.H. Rauch, Ed., American Society for Metals, Metals Park, OH, 1977, 368.



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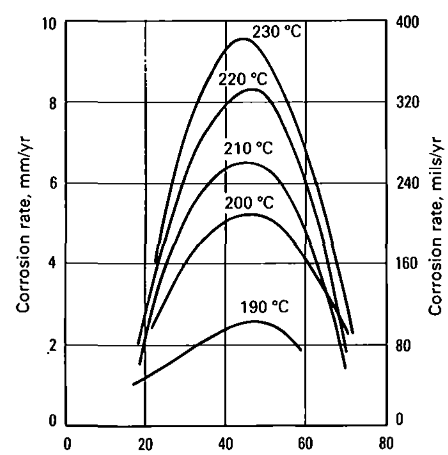
Concentration of HNO_3, %

Cast iron. Corrosion of high-silicon cast iron in nitric acid as a function of concentration and temperature. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 569.



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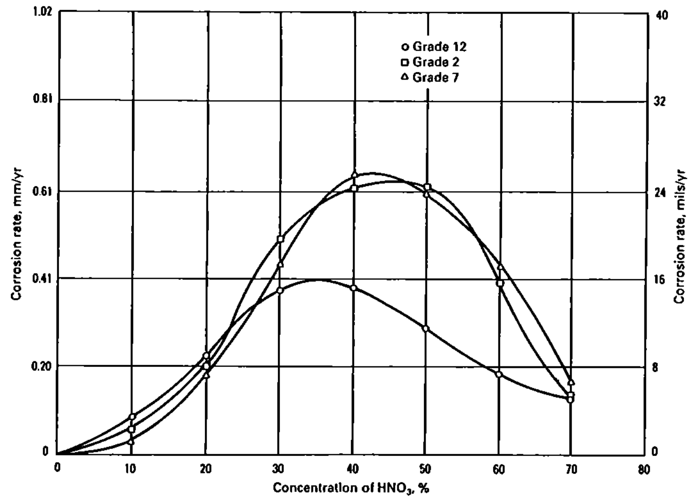
Concentration of HNO_3, %

Titanium. Corrosion of unalloyed titanium in high-temperature nitric acid solutions. Source: *Metals Handbook*, Vol 13, Corrosion, ASM International, Metals Park, OH 1987, 678.



Titanium. Corrosion of titanium alloys in boiling, uninhibited nitric acid solutions. Acid solutions were refreshed every 24 h. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 678.

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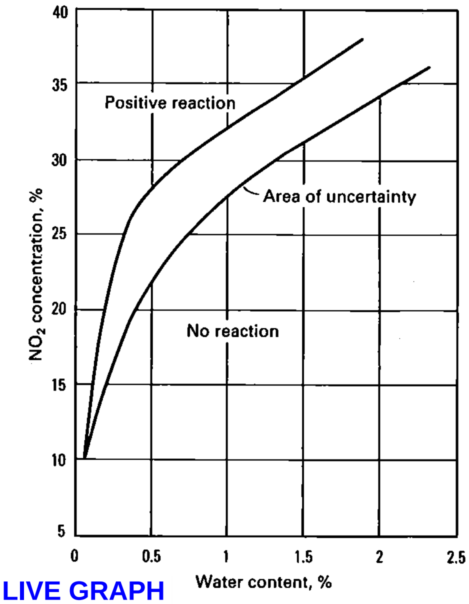

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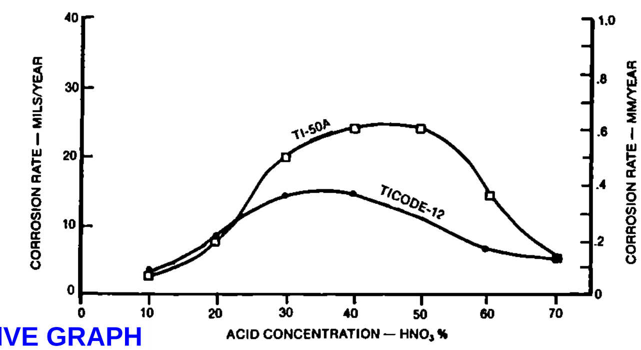
Titanium. Acid composition limits for avoiding rapid, pyrophoric reactions of titanium with red fuming nitric acid. Source: L.C. Gilbert and C.W. Fink, "Explosions of Titanium and Fuming Nitric Acid Mixtures," *Metal Progress*, Nov 1956, 93-96.



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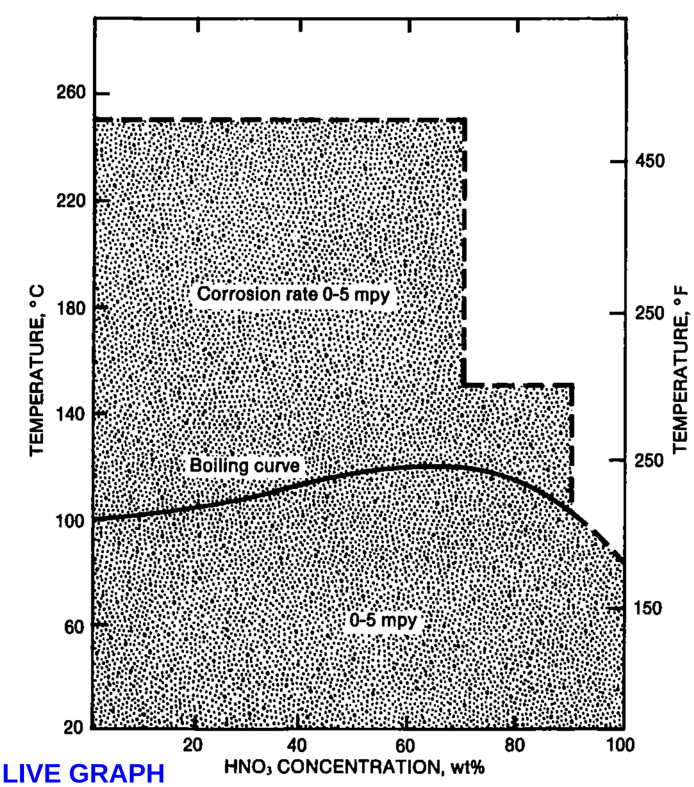
Titanium. Corrosion rate of titanium alloys in boiling nitric acid. Both titanium and titanium-palladium alloys are resistant to concentrated nitric acid from 65 to 90% and to dilute acid of less than 10%. At concentrations above 90%, however, titanium is subject to stress-corrosion cracking in nitric acid. Titanium is never used in red fuming nitric acid because a pyrophoric reaction can occur if water content is less than 1.34% and nitrous oxide exceeds 6%. Source: R.D. Crooks, "Materials of Construction for Nitric Acid," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986, 261-262.



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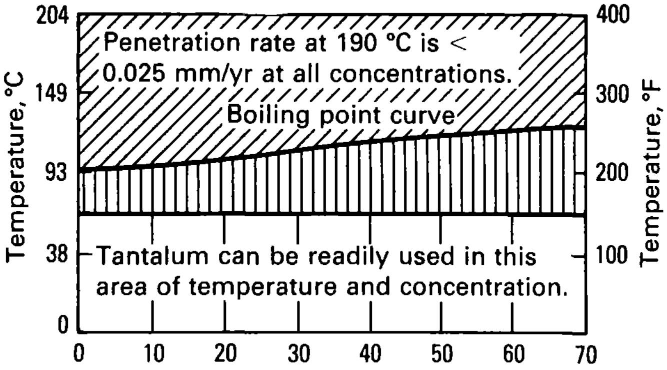
Zirconium. Corrosion of zirconium in nitric acid solutions. Source: "Zircadyne Corrosion Properties," Teledyne Wah Chang Albany, 1986.



LIVE GRAPH
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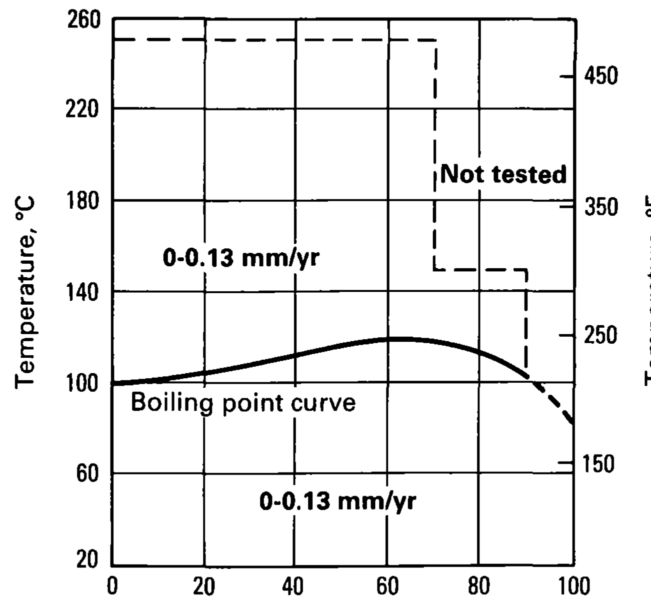
Tantalum. Corrosion resistance of tantalum in nitric acid of various concentrations and temperatures. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 731.



LIVE GRAPH
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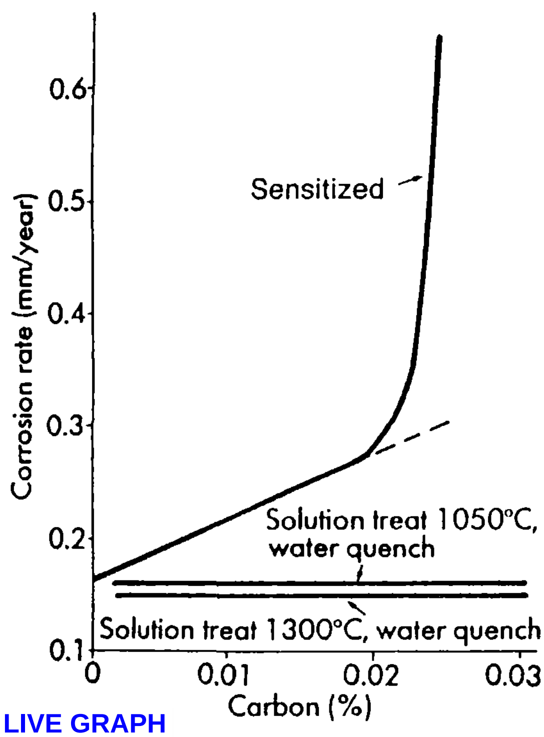
Zirconium. Isocorrosion diagram for zirconium in nitric acid. Source: "Zircadyne Corrosion Properties," Teledyne Wah Chang Albany, 1986.



LIVE GRAPH
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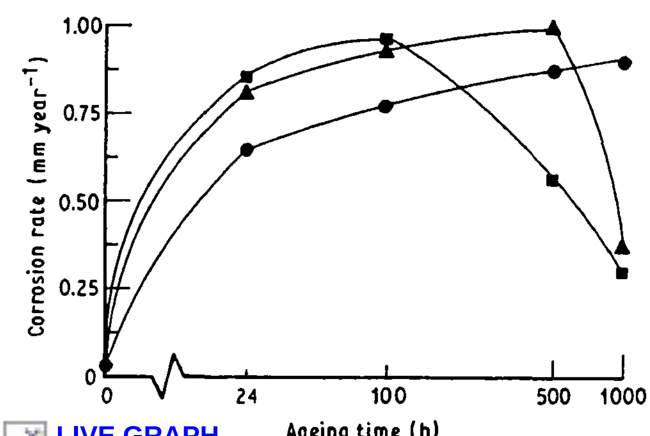
Stainless steel. Effect of carbon content on rate in boiling nitric acid (Huey) test, ASTM A 262 Practice C, of type 304L stainless steel (1 mm/y = 39.4 mpy). Ref. 269



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Key:
● = up to 1000 h at 650°C (1202°F)
▲ = up to 1000 h at 760°C (1400°F)
■ = up to 1000 h at 870°C (1598°F)

Inconel 625. Effect of thermal aging on the corrosion rate of Inconel 625 in boiling 10% nitric acid. Ref. 210

Nitric Oxide

Nitric oxide, NO, also known as nitrogen oxide and nitrogen monoxide, is a colorless gas that will react with oxygen at room temperature to form nitrogen dioxide, N_2O_2, a reddish-brown gas. It is soluble in water and alcohol and is used primarily to form other compounds.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Instrument tubing at a new facility, a combination of copper (C12200) tubing and yellow brass (C27000) fittings, failed by stress-corrosion cracking after a few weeks. The new building was located near and downwind of another facility that occasionally vented small amounts of nitric oxide. Tests showed that brass samples would fail by stress-corrosion cracking if exposed to nitric oxide emissions.

Tantalum. Tantalum resists nitric oxide (as a 5% mixture in argon) at temperatures below 1125 °C (2050 °F). However, as the temperature is increased from 1195 to 1457 °C (2180 to 2670 °F), the reaction rate increased from 0.0065 to 0.076% area loss per second.

Corrosion Behavior of Various Metals and Alloys in Nitric Oxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	Pure	Room	...	Poor	...	8

Nitric Tetroxide

Nitric tetroxide, N_2O_4, is also known as nitrogen peroxide and nitrogen dioxide, NO_2. It exists as a colorless solid, a yellow liquid, or a reddish-brown gas. It is soluble in water. Nitric tetroxide is used in the preparation of nitric acid and as an oxidizer with hydrazine rocket fuels.

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Aluminum. Aluminum alloy missile fuel tanks handle nitric tetroxide under stringent moisture control.

Titanium. Titanium alloys are highly resistant to corrosion attack in nitric tetroxide. Titanium alloys will crack in nitric tetroxide containing excess dissolved oxygen (red nitric tetroxide), but will not crack in nitric tetroxide containing nitric oxide (oxygen-free or green nitric tetroxide). Rapid, pyrophoric reactions in titanium alloys are also possible in anhydrous nitric tetroxide gas atmospheres. The addition of small amounts of water or the presence of 0.6 to 1.0 wt% nitric acid inhibits metal attack.

Corrosion Behavior of Various Metals and Alloys in Nitric Tetraoxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Silver	P07010	...	...	Pure	Room	...	0.05 (2) max	...	8

Nitrogen

Nitrogen, N_2, is a colorless, odorless, inert gas that comprises 80% of the earth's atmosphere. It serves as a diluent and controls natural burning and respiration rates, which would be much faster in higher concentrations of oxygen. Nitrogen is soluble in water and alcohol, but is essentially insoluble in most other liquids. It is essential to practically all forms of life and its compounds serve as foods or fertilizers. Nitrogen is used in the manufacture of ammonia and nitric acid. Nitrogen is essentially an inert gas at ambient and moderate temperatures. Therefore, it is easily handled by most metals. At elevated temperatures, nitrogen can be aggressive to metals and alloys.

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Aluminum. Aluminum alloy equipment has been used to process and handle liquid nitrogen.

Niobium. At 100 °C (212 °F), niobium is inert in nitrogen. Niobium does react with nitrogen at temperatures above 350 °C (660 °F).

Silver. Silver can be exposed to nitrogen up to 500 °C (930 °F).

Tantalum. Tantalum experiences an increase in hardness, tensile strength, and electrical resistivity and a decrease in elongation and density with the presence of nitrogen in only a few atomic percent concentration (one atomic percent nitrogen in tantalum equals 780 ppm nitrogen).

Tin. Below its melting point 232 °C (450 °F), tin does not react with nitrogen.

Titanium. Titanium alloys show low reaction rates in pure nitrogen atmospheres below 650 °C (1200 °F) due to the formation of a protective nitride surface film.

Zirconium. Zirconium is stable in nitrogen at temperatures up to 300 to 400 °C (570 to 750 °F).

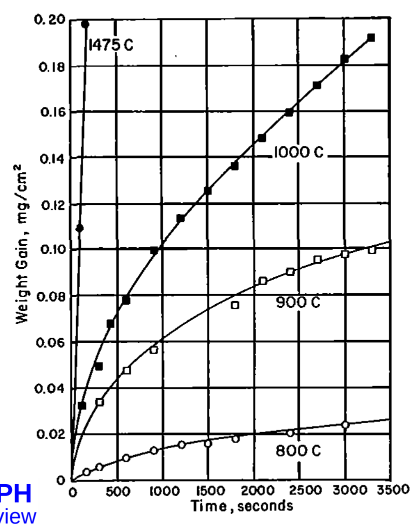
Corrosion Behavior of Various Metals and Alloys in Nitrogen

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	High	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel-silver	...	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Silver	P07010	...	...	Pure	500 (930)	...	0.05 (2) max	...	8

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitrogen (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus 6% carbon dioxide, 1% carbon monoxide, traces of butanes, pentanes, water and aldehydes	90	30-55 (86-131)	1178 d	0.003 (0.1) max	...	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation. Plus 6% carbon dioxide, 1% carbon monoxide, traces of butanes, pentanes, water and aldehydes	90	30-55 (86-131)	1178 d	0.003 (0.1) max	...	89



LIVE GRAPH
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Tantalum. Reaction of tantalum with nitrogen at various temperatures. Source: C.A. Hampel, "Tantalum," in *Rare Metals Handbook*, 2nd ed., C.A. Hampel, Ed., Reinhold Publishing, New York, 1961, 505.

Nitrosylsulfuric Acid

Nitrosylsulfuric acid, HNO_5S, is a straw-colored, oily liquid furnished as a 40% solution in 87% sulfuric acid, and stable at room temperature. It is used as a diazotizing agent for dyes, chemical intermediate, drugs and pharmaceuticals.

Corrosion Behavior of Various Metals and Alloys in Nitrosylsulfuric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
302	S30200	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
303	S30300	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
303	S30300	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitrosylsulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
304L	S30403	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316	S31600	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316	S31600	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
316F	S31620	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316L	S31603	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316L	S31603	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
316LN	S31653	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
316Ti	S31635	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
317L	S31703	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
317L	S31703	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
317LN	S31725	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
321	S32100	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
329	S32900	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
329	S32900	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253
347	S34700	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
403	S40300	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
405	S40500	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
409	S40900	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
410	S41000	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
416	S41600	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
420	S42000	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
430	S43000	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
434	S43400	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
F51	S31803	...	60 Be with 4-5% Nitro content	...	20 (68)	...	Resistant	...	253
F51	S31803	...	60 Be with 4-5% Nitro content	...	75 (167)	...	Good	...	253

Nitrous Acid

Nitrous acid, HNO_2, is the aqueous solution of nitrogen trioxide. It is a moderately strong and rapid oxidizing agent used for diazotization.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Nickel. Alloy 600 resists corrosion from nitrous acid solutions in diazotizing baths used in the application of developed color dyes. Monel alloy 400 is severely attacked by nitrous acid in solutions over 0.5% at room temperature. Chromium-containing Incoloy alloys 800 and 825 are recommended for use with nitrous acid, because the metal forms a protective passive oxide film.

Corrosion Behavior of Various Metals and Alloys in Nitrous Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitrous Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum-manganese alloys	...	...	Solution	...	...	...	Resistant	...	92
Miscellaneous									
Silver	P07010	...	...	...	Room	...	Poor	...	4
Silver	P07010	...	...	...	Room	...	Poor	...	4
Stainless steels									
301	S30100	...	...	Concentrated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Concentrated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Good	...	121
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253

Oleic Acid

Oleic acid, $C_{17}H_{33}COOH$, also known as red oil, elaine oil, and octadecenoic acid, is a yellowish unsaturated fatty acid with an aroma similar to lard. It is insoluble in water, but soluble in most organic solvents. Oleic acid is the main component in cooking and olive oils. It is used for making aluminum oleate, which thickens lubricating oil, and in the preparation of soaps and cosmetics.

Material Summaries

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Aluminum. Aluminum alloys 1100, 3003, and 6061 resisted oleic acid during laboratory tests at ambient temperature. Aluminum alloy tank cars have been used to ship oleic acid.

Cast Irons. Austenitic nickel cast irons exhibit adequate resistance to oleic acid.

Copper. Copper and copper-zinc alloys resist attack by pure oleic acid. The presence of air and water promotes the corrosion of these alloys, and temperature affects the rate of attack. Tested under conditions of 25 °C (75 °F), C51000 and C61300 had corrosion rates of less than 0.050 mm/yr (2 mils/yr) in oleic acid, whereas C26000 and C65500 had corrosion rates of 0.50 mm/yr (20 mils/yr).

Corrosion Behavior of Various Metals and Alloys in Oleic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Nitrous Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum-manganese alloys	...	...	Solution	...	...	...	Resistant	...	92
Miscellaneous									
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302	S30200	...	...	Concentrated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Concentrated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Good	...	121
434	S43400	...	...	Concentrated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253

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Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Oleic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Stainless steels									
301	S30100	...	30 bar	...	150 (302)	...	Resistant	...	253
301	S30100	...	30 bar	...	180 (356)	...	Good	...	253
301	S30100	...	30 bar	...	235 (455)	...	Good	...	253
301	S30100	...	30 bar	...	300 (572)	...	Questionable	...	253
302	S30200	...	30 bar	...	150 (302)	...	Resistant	...	253
302	S30200	...	30 bar	...	180 (356)	...	Good	...	253
302	S30200	...	30 bar	...	235 (455)	...	Good	...	253
302	S30200	...	30 bar	...	300 (572)	...	Questionable	...	253
303	S30300	...	30 bar	...	150 (302)	...	Resistant	...	253
303	S30300	...	30 bar	...	150 (302)	...	Resistant	...	253
303	S30300	...	30 bar	...	180 (356)	...	Questionable	...	253
303	S30300	...	30 bar	...	180 (356)	...	Good	...	253
303	S30300	...	30 bar	...	235 (455)	...	Questionable	...	253
303	S30300	...	30 bar	...	235 (455)	...	Good	...	253
303	S30300	...	30 bar	...	300 (572)	...	Poor	...	253
303	S30300	...	30 bar	...	300 (572)	...	Questionable	...	253
304	S30400	...	30 bar	...	150 (302)	...	Resistant	...	253
304	S30400	...	30 bar	...	180 (356)	...	Good	...	253
304	S30400	...	30 bar	...	235 (455)	...	Good	...	253
304	S30400	...	30 bar	...	300 (572)	...	Questionable	...	253
304L	S30403	...	30 bar	...	150 (302)	...	Resistant	...	253
304L	S30403	...	30 bar	...	180 (356)	...	Good	...	253
304L	S30403	...	30 bar	...	235 (455)	...	Good	...	253
304L	S30403	...	30 bar	...	300 (572)	...	Questionable	...	253
304LN	S30453	...	30 bar	...	150 (302)	...	Resistant	...	253
304LN	S30453	...	30 bar	...	180 (356)	...	Good	...	253
304LN	S30453	...	30 bar	...	235 (455)	...	Good	...	253
304LN	S30453	...	30 bar	...	300 (572)	...	Questionable	...	253
316	S31600	...	30 bar	...	150 (302)	...	Resistant	...	253
316	S31600	...	30 bar	...	180 (356)	...	Resistant	...	253
316	S31600	...	30 bar	...	235 (455)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Oleic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	30 bar	...	300 (572)	...	Resistant	...	253
316F	S31620	...	30 bar	...	150 (302)	...	Resistant	...	253
316F	S31620	...	30 bar	...	180 (356)	...	Good	...	253
316F	S31620	...	30 bar	...	235 (455)	...	Good	...	253
316F	S31620	...	30 bar	...	300 (572)	...	Questionable	...	253
316L	S31603	...	30 bar	...	150 (302)	...	Resistant	...	253
316L	S31603	...	30 bar	...	180 (356)	...	Resistant	...	253
316L	S31603	...	30 bar	...	235 (455)	...	Resistant	...	253
316L	S31603	...	30 bar	...	300 (572)	...	Resistant	...	253
316LN	S31653	...	30 bar	...	150 (302)	...	Resistant	...	253
316LN	S31653	...	30 bar	...	180 (356)	...	Resistant	...	253
316LN	S31653	...	30 bar	...	235 (455)	...	Resistant	...	253
316LN	S31653	...	30 bar	...	300 (572)	...	Resistant	...	253
316Ti	S31635	...	30 bar	...	150 (302)	...	Resistant	...	253
316Ti	S31635	...	30 bar	...	180 (356)	...	Resistant	...	253
316Ti	S31635	...	30 bar	...	235 (455)	...	Resistant	...	253
316Ti	S31635	...	30 bar	...	300 (572)	...	Resistant	...	253
317L	S31703	...	30 bar	...	150 (302)	...	Resistant	...	253
317L	S31703	...	30 bar	...	180 (356)	...	Resistant	...	253
317L	S31703	...	30 bar	...	235 (455)	...	Resistant	...	253
317L	S31703	...	30 bar	...	300 (572)	...	Resistant	...	253
317LN	S31725	...	30 bar	...	150 (302)	...	Resistant	...	253
317LN	S31725	...	30 bar	...	180 (356)	...	Resistant	...	253
317LN	S31725	...	30 bar	...	235 (455)	...	Resistant	...	253
317LN	S31725	...	30 bar	...	300 (572)	...	Resistant	...	253
321	S32100	...	30 bar	...	150 (302)	...	Resistant	...	253
321	S32100	...	30 bar	...	180 (356)	...	Good	...	253
321	S32100	...	30 bar	...	235 (455)	...	Good	...	253
321	S32100	...	30 bar	...	300 (572)	...	Questionable	...	253
329	S32900	...	30 bar	...	150 (302)	...	Resistant	...	253
329	S32900	...	30 bar	...	180 (356)	...	Resistant	...	253
329	S32900	...	30 bar	...	235 (455)	...	Resistant	...	253
329	S32900	...	30 bar	...	300 (572)	...	Resistant	...	253
347	S34700	...	30 bar	...	150 (302)	...	Resistant	...	253
347	S34700	...	30 bar	...	180 (356)	...	Good	...	253
347	S34700	...	30 bar	...	235 (455)	...	Good	...	253
347	S34700	...	30 bar	...	300 (572)	...	Questionable	...	253
403	S40300	...	30 bar	...	150 (302)	...	Resistant	...	253
403	S40300	...	30 bar	...	180 (356)	...	Questionable	...	253
403	S40300	...	30 bar	...	235 (455)	...	Poor	...	253
403	S40300	...	30 bar	...	300 (572)	...	Poor	...	253
405	S40500	...	30 bar	...	150 (302)	...	Resistant	...	253
405	S40500	...	30 bar	...	180 (356)	...	Questionable	...	253
405	S40500	...	30 bar	...	235 (455)	...	Poor	...	253
405	S40500	...	30 bar	...	300 (572)	...	Poor	...	253
409	S40900	...	30 bar	...	150 (302)	...	Resistant	...	253
409	S40900	...	30 bar	...	180 (356)	...	Questionable	...	253
409	S40900	...	30 bar	...	235 (455)	...	Poor	...	253
409	S40900	...	30 bar	...	300 (572)	...	Poor	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	30 bar	...	150 (302)	...	Resistant	...	253
410	S41000	...	30 bar	...	180 (356)	...	Questionable	...	253
410	S41000	...	30 bar	...	235 (455)	...	Poor	...	253
410	S41000	...	30 bar	...	300 (572)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Oleic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	30 bar	...	150 (302)	...	Resistant	...	253
416	S41600	...	30 bar	...	180 (356)	...	Questionable	...	253
416	S41600	...	30 bar	...	235 (455)	...	Poor	...	253
416	S41600	...	30 bar	...	300 (572)	...	Poor	...	253
420	S42000	...	30 bar	...	150 (302)	...	Resistant	...	253
420	S42000	...	30 bar	...	180 (356)	...	Questionable	...	253
420	S42000	...	30 bar	...	235 (455)	...	Poor	...	253
420	S42000	...	30 bar	...	300 (572)	...	Poor	...	253
430	S43000	...	30 bar	...	150 (302)	...	Resistant	...	253
430	S43000	...	30 bar	...	180 (356)	...	Questionable	...	253
430	S43000	...	30 bar	...	235 (455)	...	Questionable	...	253
430	S43000	...	30 bar	...	300 (572)	...	Poor	...	253
434	S43400	...	30 bar	...	150 (302)	...	Resistant	...	253
434	S43400	...	30 bar	...	180 (356)	...	Good	...	253
434	S43400	...	30 bar	...	235 (455)	...	Questionable	...	253
434	S43400	...	30 bar	...	300 (572)	...	Questionable	...	253
F51	S31803	...	30 bar	...	150 (302)	...	Resistant	...	253
F51	S31803	...	30 bar	...	180 (356)	...	Resistant	...	253
F51	S31803	...	30 bar	...	235 (455)	...	Resistant	...	253
F51	S31803	...	30 bar	...	300 (572)	...	Resistant	...	253

Oxalic Acid

Oxalic acid, HOOCCOOH·$2H_2O$, also known as ethane dioic acid, is a poisonous, colorless crystalline solid that has a melting point of 189 °C (372 °F). It is soluble in water, alcohol, and ether. Oxalic acid is used in dyeing, bleaching, ink and rust removers, metal polishes, and as a chemical intermediate in the production of oxalates and purification of glycerols.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Under laboratory conditions of ambient temperature and 100% relative humidity, aluminum alloy 3003 had a corrosion rate of 0.50 mm/yr (20 mils/yr) in solid oxalic acid. Alloy 1100 suffered corrosion of 0.375 mm/yr (15 mils/yr) in aqueous solutions (0.1 to 12% oxalic acid) during tests run at ambient temperature. These solutions were also corrosive to alloy 1100 at 50 °C (122 °F) and at boiling temperatures. Aluminum alloy filters and crystallizers have been used with oxalic acid, because the aluminum salts do not discolor the product.

Cast Irons. High-silicon cast irons exhibit excellent resistance to oxalic acid at all temperatures and concentrations.

Copper. Aluminum bronzes are generally suitable for service in oxalic acid.

Zirconium. Zirconium resists corrosion in oxalic acid.

Corrosion Behavior of Various Metals and Alloys in Oxalic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
10Cr	...	...	...	2.5	22-25	1 d	0.4 (16)	...	203
10Cr	...	...	...	5	22-25	1 d	0.6 (22)	...	203
10Cr	...	...	...	7.5	22-25	1 d	0.7 (27)	...	203

(Continued)

Corrosion Behavior of Various Metals and Alloys in Oxalic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
10Cr	...	...	...	10	22-25	1 d	0.7 (29)	...	203
10Cr	...	...	...	12.5	22-25	1 d	0.8 (31)	...	203
10Cr	...	...	...	2.5	Boiling	1 h	50 (2000)	...	203
10Cr	...	...	...	5	Boiling	1 h	60 (2380)	...	203
10Cr	...	...	...	7.5	Boiling	1 h	73 (2900)	...	203
10Cr	...	...	...	10	Boiling	1 h	82 (3290)	...	203
10Cr	...	...	...	12.5	Boiling	1 h	82 (3290)	...	203
5Cr	K51545	...	...	2.5	22-25	1 h	0.4 (16)	...	203
5Cr	K51545	...	...	5	Boiling	1 h	0.5 (18)	...	203
5Cr	K51545	...	...	7.5	Boiling	1 h	0.5 (18)	...	203
5Cr	K51545	...	...	10	Boiling	1 h	0.5 (20)	...	203
5Cr	K51545	...	...	12.5	Boiling	1 h	0.6 (24)	...	203
5Cr	K51545	...	...	2.5	Boiling	1 h	41 (1650)	...	203
5Cr	K51545	...	...	5	Boiling	1 h	46 (1830)	...	203
5Cr	K51545	...	...	7.5	Boiling	1 h	50 (2000)	...	203
5Cr	K51545	...	...	10	Boiling	1 h	53 (2100)	...	203
5Cr	K51545	...	...	12.5	Boiling	1 h	55 (2200)	...	203
Miscellaneous									
Gold	P00016	...	...	All	Boiling	...	0.05 (2) max	...	8
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Nickel and alloys									
Alloy 625	N06625	...	...	10	Boiling	...	0.20 (6.0)	...	223
Inconel 690	N06690	...	...	5	80 (176)	...	0.03 (1) max	...	57
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Refractory metals and alloys									
Niobium	R04210	...	...	10	Boiling	...	1.25 (50)	...	2
Tantalum	R05210	...	...	...	21 (70)	...	Resistant	...	42
Tantalum	R05210	...	...	...	96 (205)	...	0.003 (0.1)	...	42
Zr702	R06702	...	...	0-100	100 (212)	...	0.025 (1) max	...	15
Stainless steels									
17Cr	S43000	...	...	2.5	22-25	1 d	2.4 (96)	...	203
17Cr	S43000	...	...	5	22-25	1 d	2.7 (108)	...	203
17Cr	S43000	...	...	7.5	22-25	1 d	3.0 (120)	...	203
17Cr	S43000	...	...	10	22-25	1 d	3.0 (120)	...	203
17Cr	S43000	...	...	12.5	22-25	1 d	3.8 (150)	...	203
17Cr	S43000	...	...	2.5	Boiling	1 h	114 (4580)	...	203
17Cr	S43000	...	...	5	Boiling	1 h	137 (5490)	...	203
17Cr	S43000	...	...	7.5	Boiling	1 h	173 (6950)	...	203
17Cr	S43000	...	...	10	Boiling	1 h	215 (8600)	...	203
17Cr	S43000	...	...	12.5	Boiling	1 h	243 (9700)	...	203
301	S30100	...	...	5	20 (68)	...	Resistant	...	253
301	S30100	...	...	5	Boiling	...	Good	...	253
301	S30100	...	...	10	20 (68)	...	Good	...	253
301	S30100	...	...	10	Boiling	...	Questionable	...	253
301	S30100	...	...	25	Boiling	...	Questionable	...	253
301	S30100	...	...	50	Boiling	...	Questionable	...	253
302	S30200	...	...	5	20 (68)	...	Resistant	...	253
302	S30200	...	...	5	Boiling	...	Good	...	253
302	S30200	...	...	10	20 (68)	...	Good	...	253
302	S30200	...	...	10	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Oxalic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	25	Boiling	...	Questionable	...	253
302	S30200	...	...	50	Boiling	...	Questionable	...	253
303	S30300	...	...	5	20 (68)	...	Good	...	253
303	S30300	...	...	5	20 (68)	...	Resistant	...	253
303	S30300	...	...	5	Boiling	...	Poor	...	253
303	S30300	...	...	5	Boiling	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	25	Boiling	...	Questionable	...	253
303	S30300	...	...	50	Boiling	...	Questionable	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	10	Boiling	...	1.23 (49)	...	98
304	S30400	...	...	10	Boiling	...	1.2 (48)	...	98
304	S30400	...	...	5	20 (68)	...	Resistant	...	253
304	S30400	...	...	5	Boiling	...	Good	...	253
304	S30400	...	...	10	20 (68)	...	Good	...	253
304	S30400	...	...	10	Boiling	...	Questionable	...	253
304	S30400	...	...	25	Boiling	...	Questionable	...	253
304	S30400	...	...	50	Boiling	...	Questionable	...	253
304	S30400	...	Average of five 48-h periods	10	Boiling	...	1.22 (48)	...	81
304L	S30403	...	...	5	20 (68)	...	Resistant	...	253
304L	S30403	...	...	5	Boiling	...	Good	...	253
304L	S30403	...	...	10	20 (68)	...	Good	...	253
304L	S30403	...	...	10	Boiling	...	Questionable	...	253
304L	S30403	...	...	25	Boiling	...	Questionable	...	253
304L	S30403	...	...	50	Boiling	...	Questionable	...	253
304LN	S30453	...	...	5	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	5	Boiling	...	Good	...	253
304LN	S30453	...	...	10	20 (68)	...	Good	...	253
304LN	S30453	...	...	10	Boiling	...	Questionable	...	253
304LN	S30453	...	...	25	Boiling	...	Questionable	...	253
304LN	S30453	...	...	50	Boiling	...	Questionable	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316	S31600	...	...	5	Boiling	...	Good	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Questionable	...	253
316	S31600	...	...	25	Boiling	...	Questionable	...	253
316	S31600	...	Base metal	10	Boiling	...	1.02 (40)	...	120
316	S31600	...	Welded sample	10	Boiling	...	0.99 (39)	...	120
316F	S31620	...	...	5	20 (68)	...	Resistant	...	253
316F	S31620	...	...	5	Boiling	...	Good	...	253
316F	S31620	...	...	10	20 (68)	...	Good	...	253
316F	S31620	...	...	10	Boiling	...	Questionable	...	253
316F	S31620	...	...	25	Boiling	...	Questionable	...	253
316F	S31620	...	...	50	Boiling	...	Questionable	...	253
316L	S31603	...	...	10	Boiling	...	1.20 (48)	...	223
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	Boiling	...	Good	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Questionable	...	253

(Continued)

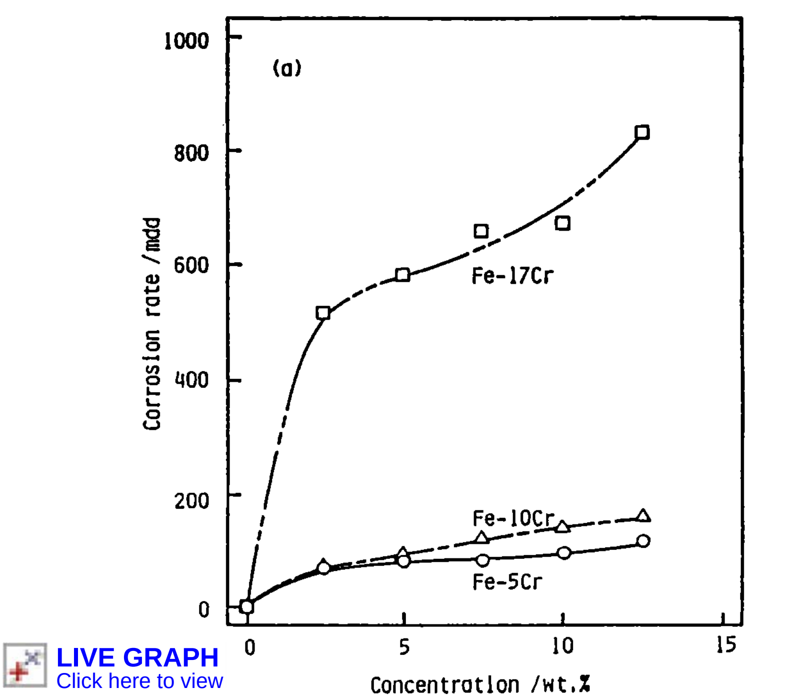
Corrosion Behavior of Various Metals and Alloys in Oxalic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	25	Boiling	...	Questionable	...	253
316L	S31603	...	Base metal	10	Boiling	...	1.02 (40)	...	120
316L	S31603	...	Welded sample	10	Boiling	...	0.99 (39)	...	120
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	Boiling	...	Good	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Questionable	...	253
316LN	S31653	...	...	25	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	Boiling	...	Good	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	25	Boiling	...	Questionable	...	253
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	5	Boiling	...	Good	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Questionable	...	253
317L	S31703	...	...	25	Boiling	...	Questionable	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	Boiling	...	Good	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Questionable	...	253
317LN	S31725	...	...	25	Boiling	...	Questionable	...	253
321	S32100	...	...	5	20 (68)	...	Resistant	...	253
321	S32100	...	...	5	Boiling	...	Good	...	253
321	S32100	...	...	10	20 (68)	...	Good	...	253
321	S32100	...	...	10	Boiling	...	Questionable	...	253
321	S32100	...	...	25	Boiling	...	Questionable	...	253
321	S32100	...	...	50	Boiling	...	Questionable	...	253
329	S32900	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	Boiling	...	Good	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Questionable	...	253
329	S32900	...	...	25	Boiling	...	Questionable	...	253
347	S34700	...	...	5	20 (68)	...	Resistant	...	253
347	S34700	...	...	5	Boiling	...	Good	...	253
347	S34700	...	...	10	20 (68)	...	Good	...	253
347	S34700	...	...	10	Boiling	...	Questionable	...	253
347	S34700	...	...	25	Boiling	...	Questionable	...	253
347	S34700	...	...	50	Boiling	...	Questionable	...	253
403	S40300	...	...	5	20 (68)	...	Good	...	253
405	S40500	...	...	5	20 (68)	...	Good	...	253
409	S40900	...	...	10	Boiling	...	45 (1800)	...	98
409	S40900	...	...	5	20 (68)	...	Good	...	253
410	S41000	...	...	10	21 (70)	...	Poor	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	5	20 (68)	...	Good	...	253
416	S41600	...	...	5	20 (68)	...	Good	...	253
420	S42000	...	...	5	20 (68)	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	Boiling	...	110 (4300)	...	98
430	S43000	...	...	5	20 (68)	...	Good	...	253

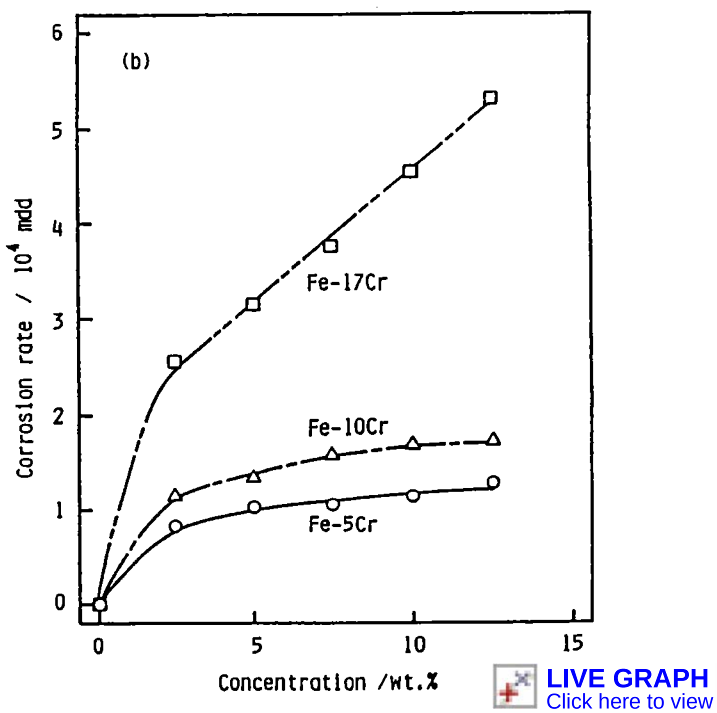
(Continued)

Corrosion Behavior of Various Metals and Alloys in Oxalic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	5	Boiling	...	Poor	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
434	S43400	...	...	5	20 (68)	...	Resistant	...	253
434	S43400	...	...	5	Boiling	...	Poor	...	253
434	S43400	...	...	10	20 (68)	...	Questionable	...	253
434	S43400	...	...	10	Boiling	...	Poor	...	253
434	S43400	...	...	25	Boiling	...	Poor	...	253
434	S43400	...	...	50	Boiling	...	Poor	...	253
439	S43035	...	...	10	Boiling	...	54 (2160)	...	98
439	S43035	...	...	10	Boiling	...	55 (2180)	...	223
444	S44400	...	...	10	Boiling	...	59 (2340)	...	223
AL 2205	S31803	...	Base metal	10	Boiling	...	0.20 (7.8)	...	120
AL 2205	S31803	...	Welded sample	10	Boiling	...	0.13 (5.1)	...	120
AL 29-4-2	S44800	...	...	10	Boiling	...	0.02 (0.7)	...	81
AL 29-4-2	S44800	...	...	10	Boiling	...	0.02 (0.7)	...	223
AL 29-4C	S44735	...	...	10	Boiling	...	0.01 (0.5)	...	223
AL 6XN	N08367	...	Base metal	10	Boiling	...	0.28 (11)	...	120
AL 6XN	N08367	...	Welded sample	10	Boiling	...	0.27 (11)	...	120
AL 904L	N08904	...	...	10	Boiling	...	0.69 (27)	...	120
ALPHA-2	...	...	...	10	Boiling	...	120 (4800)	...	98
Altemp A-286	K66286	...	...	10	Boiling	...	0.37 (14)	...	98
E-Brite	S44627	...	...	10	Boiling	...	0.10 (3.0)	...	223
E-Brite	S44627	...	Average of five 48-h periods	10	Boiling	...	0.076 (3)	...	81
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	5	Boiling	...	Good	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Questionable	...	253
F51	S31803	...	...	25	Boiling	...	Questionable	...	253



Fe-Cr alloys. Corrosion rate of Fe-Cr alloys versus concentration of $(COOH)_2$ solution at room temperature. Ref. 203



Fe-Cr alloys. Corrosion rate of Fe-Cr alloys versus concentration of $(COOH)_2$ solution at boiling point. Ref. 203

Oxygen

Oxygen, O_2, is a colorless, tasteless, gaseous element essential to almost all forms of life. It promotes respiration and combustion. Oxygen comprises 20% of the earth's atmosphere and is the most abundant element in seawater and in the earth's crust. It is slightly soluble in water and alcohol, but combines readily with most other elements to form oxides. The electrolysis of water produces both oxygen and hydrogen. Direct uses of oxygen are in welding, in metal-cutting, and in medicine. A purity of 99.5% oxygen is required for oxyacetylene torches, and a reduction of 0.5% decreases the welding efficiency by over 10%. Oxyhydrogen torches provide lower temperatures that are useful for welding light-gage aluminum and magnesium alloys and for underwater cutting.

Oxygen is very reactive with organic compounds like oil and grease. Therefore, equipment used to handle oxygen should be cleaned with great care.

Metal corrosion is influenced by the presence of oxidizing agents. On the positive side, oxidizing agents promote the formation of a protective oxide film on the surface of some metals such as aluminum, which prevents further corrosion. However, in some situations, oxidizing agents promote cathodic reactions that increase the corrosion rates. A dramatic example is the corrosion of Monel, which resisted attack by oxygen-free 5% sulfuric acid at room temperature, but with the addition of oxygen corroded at a rate in almost a direct proportion to the oxygen content. The oxygen need not be present in the entire acid, but only at the interface of metal, acid, and surrounding atmosphere.

Feedwater with dissolved oxygen will pit the internal surfaces of boiler, steel drum, economizer, and supply tubes. This corrosion in either the operating boiler or improperly stored idle boiler will reduce the reliability and the service life of the equipment.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys retain mechanical properties at low temperatures and are therefore used in the manufacture, handling, and shipping of liquid oxygen. Valves of alloy A356.0 have been employed in the service of liquid oxygen. Aluminum has the lowest resistance to ignition in oxygen service of common metals.

Copper. Hospital oxygen systems use copper and copper alloy tubing to handle oxygen at room temperature. A copper oxide film forms when copper is heated in air or oxygen. At temperatures below 100 °C (212 °F), the film thickness increases logarithmically with time. An increase in temperature allows the scaling rate to increase irregularly, but the addition of pressure up to 1.6 kPa (12 torr) allows the rate to rise rapidly. The scaling rate increase is steady above 20 kPa (150 torr). The oxidation rate of copper is not affected by the presence of low concentrations of lead, oxygen, zinc, nickel, and phosphorus. However, the presence of silicon, magnesium, beryllium, and aluminum retard oxidation by forming a protective oxide film on the surface of copper.

Gold. Gold is resistant to oxygen to its melting point of 1063 °C (1945 °F).

Titanium. Titanium is not considered a suitable material for pure oxygen service.

Zirconium. Zirconium reacts with oxygen at temperatures above 540 °C (1000 °F) to form a white porous film of zirconium dioxide that is brittle. Prolonged exposure at temperatures above 700 °C (1290 °F) allows zirconium to absorb oxygen and become embrittled. Zirconium is not considered a suitable material for pure oxygen service.

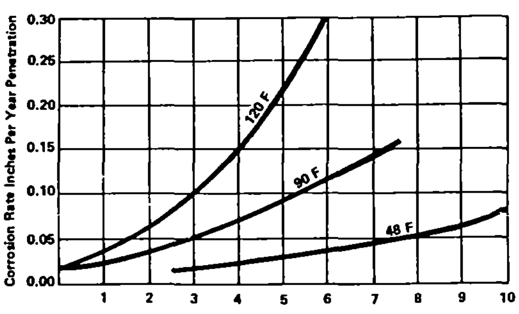
Corrosion Behavior of Various Metals and Alloys in Oxygen

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	250 (482) max	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	...	...	250-500 (482-932)	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Resistant	...	93
Brass	...	...	...	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Oxygen (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cartridge brass	C26000	...	...	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Resistant	...	93
Naval brass	C46400	...	...	...	...	...	Resistant	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Silver	P07010	...	Attack becomes appreciable at 200°C (390°F)	Pure	100 (212)	...	0.05 (2) max	...	8
Zinc	Z13001	...	Boiled distilled water, specimens immersed in sealed flasks	...	Room	7 d	0.03 (1.0)	...	140
Zinc	Z13001	...	Boiled distilled water, specimens immersed in sealed flasks	...	40 (104)	7 d	0.05 (1.9)	...	140
Zinc	Z13001	...	Boiled distilled water, specimens immersed in sealed flasks	...	65 (149)	7 d	0.08 (3.3)	...	140
Zinc	Z13001	...	Oxygen bubbled slowly through the water	...	Room	7 d	0.22 (8.6)	...	140
Zinc	Z13001	...	Oxygen bubbled slowly through the water	...	40 (104)	7 d	0.34 (13.7)	...	140
Zinc	Z13001	...	Oxygen bubbled slowly through the water	...	65 (149)	7 d	0.31 (12.4)	...	140



LIVE GRAPH
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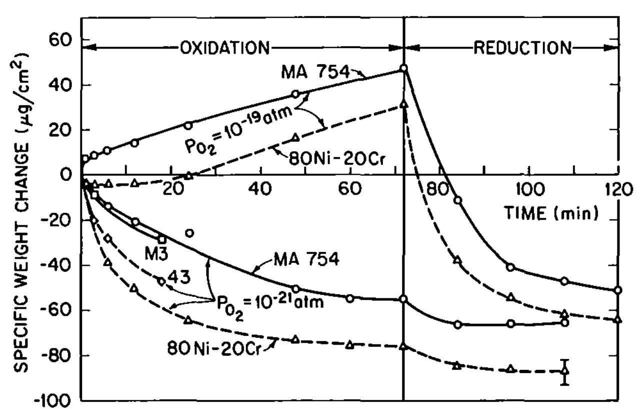
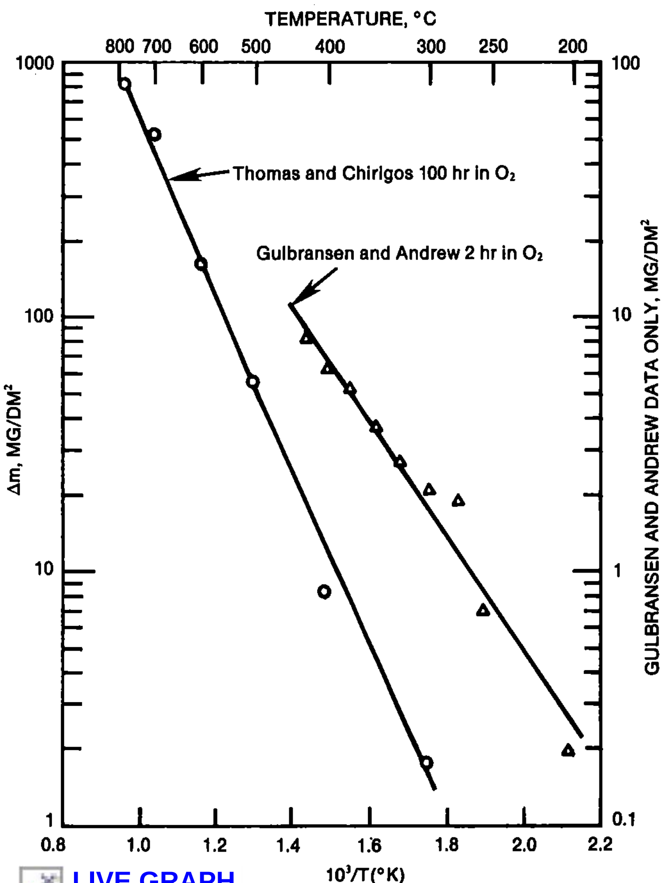
Low-carbon steel. Effect of oxygen concentration on the corrosion of low-carbon steel in tap water at different temperatures. Source: Betz Laboratories, Inc., Advertisement, *Materials Protection, 4*(10), 1965, 21.



Alloy MA 754. Results of the kinetics experiments at $P_{O2} = 10^{-19}$ and 10^{-21} atm. Note that after 72 min, the specimens were subjected to reducing conditions in pure H_2. Alloy MA 754 contains 0.6% Y_2O_3; alloy 80Ni-20Cr contains no Y_2O_3. Source: D.N. Braski, P.D. Goodell, *et. al.,* "Effect of Y_2O_3 Dispersoids in 80Ni-20Cr Alloy on the Early Stages of Oxidation at Low-Oxygen Potential," *Oxidation of Metals,* Vol 25, Feb 1986, 34.



LIVE GRAPH
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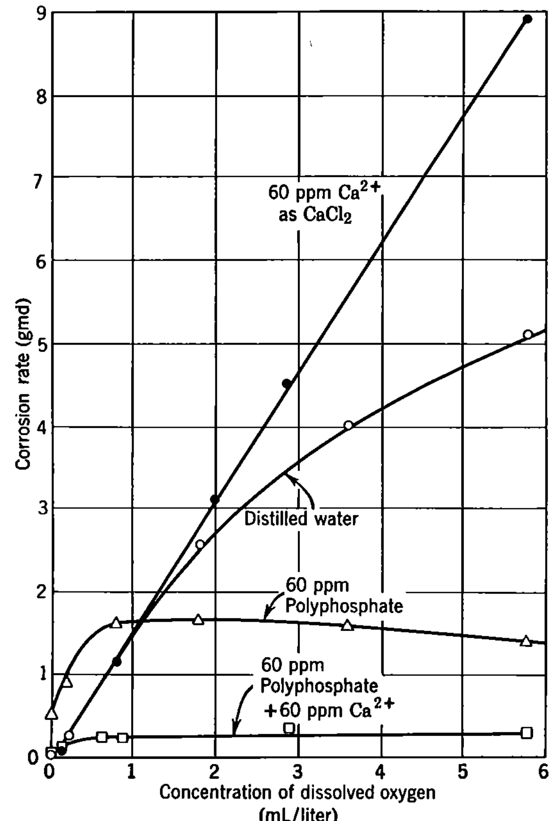
Zirconium. Effect of temperature on the corrosion of zirconium in oxygen. Source: B. Lustman, "Corrosion of Zirconium and Its Alloys," in *Metallurgy of Zirconium*, B. Lustman and F. Kerze, Ed., McGraw-Hill, New York, 1955, 614.



LIVE GRAPH
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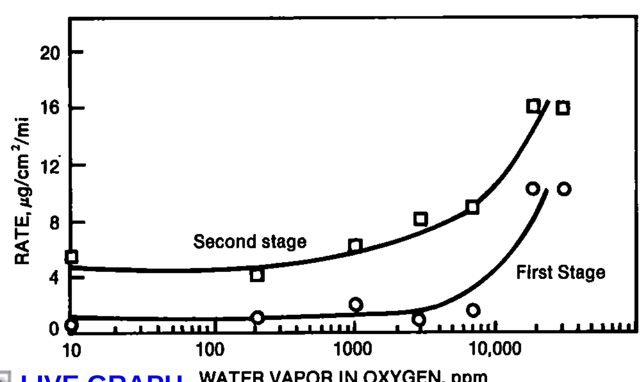
Iron. Effect of oxygen concentration on sodium polyphosphate as a corrosion inhibitor of iron showing beneficial effect of dissolved O_2 and Ca^{2+} during a 48-h test at 25 °C. Source: H.H. Uhlig and R.W. Revie, *Corrosion and Corrosion Engineering: An Introduction to Corrosion Science and Engineering*, 3rd ed., John Wiley & Sons, New York, 1985, 267.



LIVE GRAPH
Click here to view

Uranium. Effect of water vapor on reaction of uranium (1-cm cubes) in oxygen at 200 °C. Source: J.H. Gittus, *Uranium*, Butterworths, Washington, DC, 1963, 396.

Ozone

Ozone, O_3, also known as activated oxygen, is an allotropic form of oxygen formed in nature by lightning in air and during evaporation of water particularly by spray in the sea. It is an unstable blue gas with a distinctive odor. Ozone absorbs ultraviolet rays and acts as a natural blanket that protects the earth from harmful short-wave radiation from the sun. Ozone is a powerful oxidizer. It is used as an oxidant in the rubber industry, as a bleaching agent, as a water purifier, and to treat industrial wastes.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Ozonizers have been constructed of aluminum alloys.

Gold. Gold is resistant to ozone up to 100 °C (212 °F).

Silver. Ozone reacts with silver to form silver peroxide at 220 to 250 °C (430 to 480 °F). This black tarnish disappears above about 455 °C (850 °F).

Corrosion Behavior of Various Metals and Alloys in Ozone

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Dry	...	20 (68)	...	Resistant	...	92
Miscellaneous									
Gold	P00016	...	With 98% oxygen	...	100 (212)	...	0.05 (2) max	...	8
Platinum	P04995	...	With 98% oxygen	...	100 (212)	...	0.05 (2) max	...	6
Silver	P07010	...	With 98% oxygen	...	Room	...	0.05 (2) max	...	8
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Ozone in air plus approx. 0.1 mg/L nitrogen pentoxide	0.23	Room	60 d	0.003 (0.1)	...	89
304	S30400	...	Water treatment; strong aeration; rapid agitation. Ozonated tap water	...	2-21 (35-70)	105 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Ozone in air plus approx. 0.1 mg/L nitrogen pentoxide	0.23	Room	60 d	0.01 (0.4)	...	89
316	S31600	...	Water treatment; strong aeration; rapid agitation. Ozonated tap water	...	2-21 (35-70)	105 d	0.003 (0.1) max	...	89

Paraffin

Also known as alkane, this is any of a class of saturated aliphatic hydrocarbons having a straight or branched carbon chain and the general formula C_nH_{2n+2}, ranging in physical form from methane gases to waxy solids and is found mainly in Pennsylvania and midcontinent petroleum.

Ozone

Ozone, O_3, also known as activated oxygen, is an allotropic form of oxygen formed in nature by lightning in air and during evaporation of water particularly by spray in the sea. It is an unstable blue gas with a distinctive odor. Ozone absorbs ultraviolet rays and acts as a natural blanket that protects the earth from harmful short-wave radiation from the sun. Ozone is a powerful oxidizer. It is used as an oxidant in the rubber industry, as a bleaching agent, as a water purifier, and to treat industrial wastes.

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Corrosion Behavior of Various Metals and Alloys in Ozone

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Dry	...	20 (68)	...	Resistant	...	92
Miscellaneous									
Gold	P00016	...	With 98% oxygen	...	100 (212)	...	0.05 (2) max	...	8
Platinum	P04995	...	With 98% oxygen	...	100 (212)	...	0.05 (2) max	...	6
Silver	P07010	...	With 98% oxygen	...	Room	...	0.05 (2) max	...	8
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Ozone in air plus approx. 0.1 mg/L nitrogen pentoxide	0.23	Room	60 d	0.003 (0.1)	...	89
304	S30400	...	Water treatment; strong aeration; rapid agitation. Ozonated tap water	...	2-21 (35-70)	105 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; slight to moderate agitation. Ozone in air plus approx. 0.1 mg/L nitrogen pentoxide	0.23	Room	60 d	0.01 (0.4)	...	89
316	S31600	...	Water treatment; strong aeration; rapid agitation. Ozonated tap water	...	2-21 (35-70)	105 d	0.003 (0.1) max	...	89

Paraffin

Also known as alkane, this is any of a class of saturated aliphatic hydrocarbons having a straight or branched carbon chain and the general formula C_nH_{2n+2}, ranging in physical form from methane gases to waxy solids and is found mainly in Pennsylvania and midcontinent petroleum.

Perchloric Acid

Perchloric acid, $HClO_4$, also known as Fraude's reagent, is a colorless, fuming, hygroscopic liquid that boils at 16 °C (61 °F). It is a strong oxidizer and is soluble in water. Cold dilute perchloric acid reacts with metals such as zinc and iron to yield hydrogen gas and the metallic perchlorate. Perchloric acid is used in electrolytic baths, electropolishing, explosives, analytical chemistry, and medicine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Perchloric acid is very corrosive to aluminum alloys.

Tantalum. Tantalum is not attacked by perchloric acid at ordinary temperatures.

Titanium. Titanium alloys are generally highly resistant to perchloric acid over a wide range of concentrations and temperatures.

Corrosion Behavior of Various Metals and Alloys in Perchloric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Zr702	R60702	...	...	70	100 (212)	...	0.05 (2) max	...	15

Petroleum Oils

Petroleum oils comprise a mixture of hydrocarbons including the liquid paraffin series, C_5H_{12} to $C_{16}H_{34}$, the cycloparaffin or naphthene series, $C_{17}H_{36}$ to $C_{27}H_{56}$, and the gases, CH_4 to C_4H_{10}. Petroleum is a heavy, flammable oil that is formed by the decomposition of animal and plant remains by fermentation or bacterial action in a low-temperature, high-pressure reaction. Crude oil may be designated as "sour" if it contains sulfur compounds. Petroleum is used mainly in the production of fuels and lubricants, but also provides raw materials for a wide range of chemicals called petrochemicals.

The corrosivity of petroleum oils during refining is related to original constituents such as hydrogen sulfide, carbon dioxide, and other sulfur-bearing chlorides, and heavy metals and products formed during refining. The reader is encouraged to pursue the corrosivity of each of these individual compounds rather than expect the data herein to be sufficient.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon steel. The majority of petroleum oils are handled successfully with carbon steel equipment. Corrosion of steel in petroleum oils is almost always the result of associated sulfur compounds, carbon dioxide gas, or salts in the oil.

Aluminum. Aluminum alloy equipment has been used for pipelines, distillation columns, heat exchangers, storage tanks, piping, and valves handling petroleum oils because of its superior corrosion resistance compared to that of steel. However, due to the corrosive nature of some of the brines found in oil wells, it is necessary to test the brine of a specific oil field before use in aluminum alloy equipment. Sour crude (crude that contains sulfur compounds) that has previously been in contact with steel equipment may contain iron sulfide scale, which if deposited on the aluminum alloy equipment poses a corrosion hazard.

Corrosion Behavior of Various Metals and Alloys in Petroleum Oils

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Al 2014	...	As cast	Fresh SAE 30 oil	100	Room	56 d	.005 (0.18)	...	209
Al 2014	...	Heat treated	Fresh SAE 30 oil	100	Room	56 d	.003 (0.11)	...	209
Al 2014	...	Graphite composite, As cast	Fresh SAE 30 oil	100	Room	56 d	.008 (0.31)	...	209
Al 2014	...	Graphite composite, Heat treated	Fresh SAE 30 oil	100	Room	56 d	.003 (0.13)	...	209
Al 2014	...	As cast	Used SAE 30 oil	100	Room	56 d	.008 (0.33)	...	209
Al 2014	...	Heat treated	Used SAE 30 oil	100	Room	56 d	.003 (0.10)	...	209
Al 2014	...	Graphite composite, As cast	Used SAE 30 oil	100	Room	56 d	.011 (0.42)	...	209
Al 2014	...	Graphite composite, Heat treated	Used SAE 30 oil	100	Room	56 d	.004 (0.14)	...	209
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Crude oil	...	250-500 (482-932)	...	Resistant	...	92
Aluminum (99.0-99.5%)	A91199	...	Oils	...	250 (482) max	...	Resistant	...	92
Aluminum-manganese alloys	...	...	...	...	...	...	Resistant	...	92
Aluminum-manganese	...	...	Crude oil	...	250-500 (482-932)	...	Resistant	...	92
Carbon and alloy steels									
API N80	...	...	Crude oil, 0.8 MPa Ar. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	90	70 (158)	24 h	0.41	...	181
API N80	...	...	Crude oil, 0.8 MPa Ar. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	90	70 (158)	24 h	0.36	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	90	70 (158)	24 h	0.24	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	90	70 (158)	24 h	0.30	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	90	70 (158)	24 h	0.48	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	90	70 (158)	24 h	0.13	...	181

(Continued)

Corrosion Behavior of Various Metals and Alloys in Petroleum Oils (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	95	70 (158)	24 h	0.04	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	95	70 (158)	24 h	0.03	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	95	70 (158)	24 h	0.13	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	95	70 (158)	24 h	0.10	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polorization in hydrocarbon/water mixture	98	70 (158)	24 h	0.02	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2 + 20 ppm H_2S. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	98	70 (158)	24 h	0.04	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	90	70 (158)	24 h	0.30	...	181
API N80	...	...	Crude oil, 0.8 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	90	70 (158)	24 h	0.28	...	181
API N80	...	...	Crude oil, 5.2 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	90	85 (186)	24 h	0.01	...	181
API N80	...	...	Crude oil, 5.2 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	90	85 (186)	24 h	0.008	...	181

(Continued)

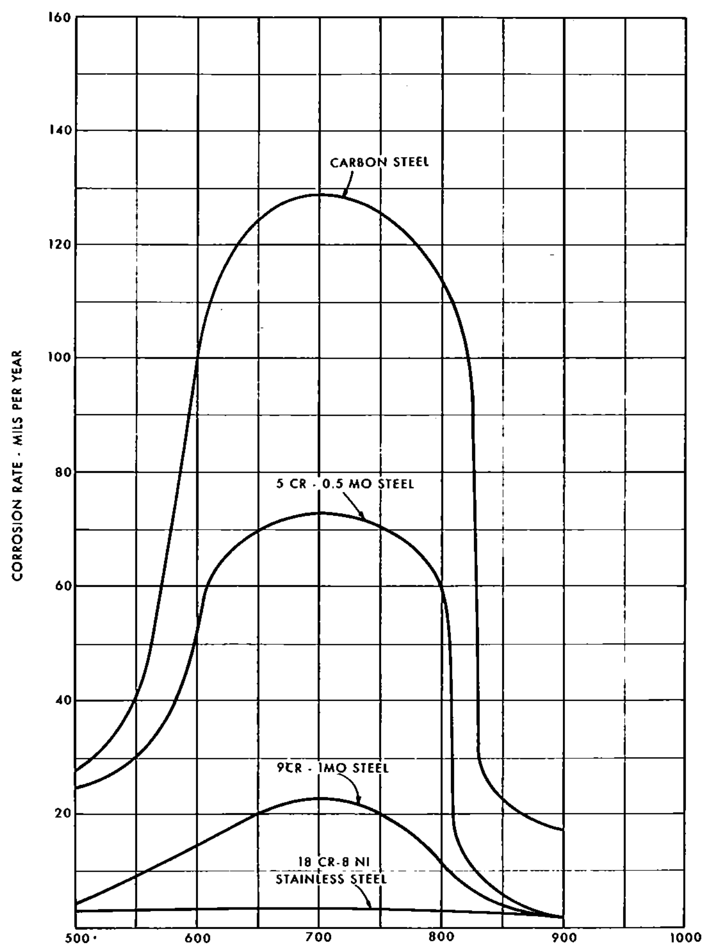
Corrosion Behavior of Various Metals and Alloys in Petroleum Oils (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
API N80	...	...	Crude oil, 5.2 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by coupon weight loss in hydrocarbon/water mixture	95	85 (186)	24 h	0.08	...	181
API N80	...	...	Crude oil, 5.2 MPa CO_2. Mixture conditioned with steel before test. Corrosion rate determined by electrochemical probe linear polarization in hydrocarbon/water mixture	95	85 (186)	24 h	0.11	...	181
Copper and alloys									
Ampco 8, Aluminum bronze	C61300	...	Refined	...	...	...	0.05 (2) max	...	96
Ampco 8, Aluminum bronze	C61300	...	Sour	...	...	...	0.5 (20) max	...	96
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Petroleum Oils (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	Petrol (gasoline)	...	Room	...	Resistant	...	121
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253



LIVE GRAPH
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Steel. Corrosion of steels in crude oil containing 1.5% sulfur. Source: J.F. Bosich, *Corrosion Prevention for Practicing Engineers*, Barnes & Noble, New York, 1970, 214.

Phenol

Phenol, C_6H_5OH, also known as carbolic acid and phenylic acid, is a white poisonous crystalline solid that melts at 43 °C (110 °F) and boils at 182 °C (360 °F). Phenol has a sharp burning taste, a distinctive odor, and it irritates tissue. It is toxic not only by ingestion or inhalation, but also by skin absorption. Phenol is soluble in water, alcohol, and ether. It is used in the production of resins, germicides, weed killers, pharmaceuticals, and as a solvent in the refining of lubricating oils.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 resisted attack by anhydrous phenol up to 50 °C (122 °F), but was mildly affected, 0.125 mm/yr (5 mils/yr), by aqueous solutions. Anhydrous phenol proved very corrosive at higher temperatures. Aluminum alloy drums, tubes, and A356.0 valves have been used to handle phenol.

Nickel. Nickel 200 protects phenol from contamination and discoloration and is therefore used to line steel storage tanks and tank cars.

Corrosion Behavior of Various Metals and Alloys in Phenol

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Questionable	...	92
Aluminum-manganese alloys	...	...	...	...	...	...	Questionable	...	92
Copper and alloys									
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Miscellaneous									
Gold	P00016	...	...	All	Boiling	...	0.05 (2) max	...	7
Lead	L50045	...	...	90	24 (75)	...	0.5 (20) max	...	95
Lead	L50045	...	During sulfonation with 93% H_2SO_4 (66°Be)	...	120 (248)	...	0.075 (3)	...	48
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	6
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	10
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	25 (77)	...	0.102 (4.08)	...	90
ZR702	R60702	...	...	Saturated	Room	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
301	S30100	...	Pure	...	Boiling	...	Good	...	253
301	S30100	...	Raw	90%	Boiling	...	Good	...	253
302	S30200	...	...	88	185 (365)	...	0.01 (0.2)	...	139
302	S30200	...	...	88	53 (125)	...	0.01 (0.2)	...	139
302	S30200	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
302	S30200	...	Pure	...	Boiling	...	Good	...	253
302	S30200	...	Raw	90%	Boiling	...	Good	...	253
303	S30300	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
303	S30300	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
303	S30300	...	Pure	...	Boiling	...	Good	...	253

(Continued)

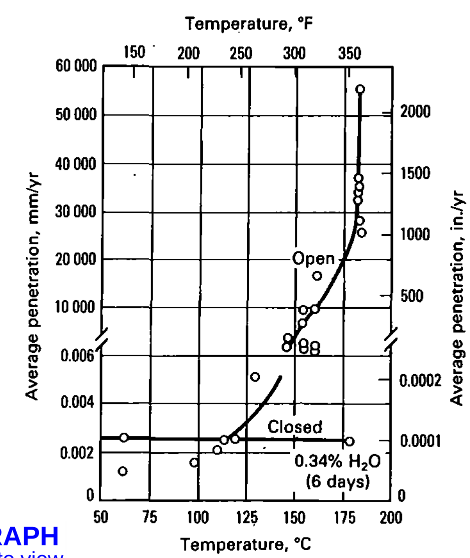
Corrosion Behavior of Various Metals and Alloys in Phenol (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	Pure	...	Boiling	...	Good	...	253
303	S30300	...	Raw	90%	Boiling	...	Poor	...	253
303	S30300	...	Raw	90%	Boiling	...	Good	...	253
304	S30400	...	...	100	315 (600)	...	0.03 (1)	...	139
304	S30400	...	Chemically pure	...	21 (70)	...	Good	...	121
304	S30400	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
304	S30400	...	Pure	...	Boiling	...	Good	...	253
304	S30400	...	Raw	90%	Boiling	...	Good	...	253
304L	S30403	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
304L	S30403	...	Pure	...	Boiling	...	Good	...	253
304L	S30403	...	Raw	90%	Boiling	...	Good	...	253
304LN	S30453	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
304LN	S30453	...	Pure	...	Boiling	...	Good	...	253
304LN	S30453	...	Raw	90%	Boiling	...	Good	...	253
310	S31000	...	...	100	315 (600)	...	0.03 (1)	...	139
316	S31600	...	...	10	105 (220)	...	Resistant	...	139
316	S31600	...	...	88	53 (125)	...	0.01 (0.2)	...	139
316	S31600	...	...	88	185 (365)	...	0.01 (0.2)	...	139
316	S31600	...	...	100	315 (600)	...	0.03 (1)	...	139
316	S31600	...	Chemically pure	...	21 (70)	...	Good	...	121
316	S31600	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
316	S31600	...	Pure	...	Boiling	...	Resistant	...	253
316	S31600	...	Raw	90%	Boiling	...	Resistant	...	253
316F	S31620	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
316F	S31620	...	Pure	...	Boiling	...	Good	...	253
316F	S31620	...	Raw	90%	Boiling	...	Good	...	253
316L	S31603	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
316L	S31603	...	Pure	...	Boiling	...	Resistant	...	253
316L	S31603	...	Raw	90%	Boiling	...	Resistant	...	253
316LN	S31653	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Pure	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Raw	90%	Boiling	...	Resistant	...	253
316Ti	S31635	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Pure	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Raw	90%	Boiling	...	Resistant	...	253
317L	S31703	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
317L	S31703	...	Pure	...	Boiling	...	Resistant	...	253
317L	S31703	...	Raw	90%	Boiling	...	Resistant	...	253
317LN	S31725	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Pure	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Raw	90%	Boiling	...	Resistant	...	253
321	S32100	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
321	S32100	...	Pure	...	Boiling	...	Good	...	253
321	S32100	...	Raw	90%	Boiling	...	Good	...	253
329	S32900	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
329	S32900	...	Pure	...	Boiling	...	Resistant	...	253
329	S32900	...	Raw	90%	Boiling	...	Resistant	...	253
347	S34700	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
347	S34700	...	Pure	...	Boiling	...	Good	...	253
347	S34700	...	Raw	90%	Boiling	...	Good	...	253
403	S40300	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
403	S40300	...	Pure	...	Boiling	...	Questionable	...	253
403	S40300	...	Raw	90%	Boiling	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phenol (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
405	S40500	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
405	S40500	...	Pure	...	Boiling	...	Questionable	...	253
405	S40500	...	Raw	90%	Boiling	...	Poor	...	253
409	S40900	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
409	S40900	...	Pure	...	Boiling	...	Questionable	...	253
409	S40900	...	Raw	90%	Boiling	...	Poor	...	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	Chemically pure	...	21 (70)	...	Good	...	121
410	S41000	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
410	S41000	...	Pure	...	Boiling	...	Questionable	...	253
410	S41000	...	Raw	90%	Boiling	...	Poor	...	253
416	S41600	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
416	S41600	...	Pure	...	Boiling	...	Questionable	...	253
416	S41600	...	Raw	90%	Boiling	...	Poor	...	253
420	S42000	...	Plus 10% H_2O	...	Boiling	...	Poor	...	253
420	S42000	...	Pure	...	Boiling	...	Questionable	...	253
420	S42000	...	Raw	90%	Boiling	...	Poor	...	253
430	S43000	...	...	10	105 (220)	...	Resistant	...	139
430	S43000	...	Chemically pure	...	21 (70)	...	Good	...	121
430	S43000	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
430	S43000	...	Pure	...	Boiling	...	Good	...	253
430	S43000	...	Raw	90%	Boiling	...	Poor	...	253
434	S43400	...	Plus 10% H_2O	...	Boiling	...	Good	...	253
434	S43400	...	Pure	...	Boiling	...	Good	...	253
434	S43400	...	Raw	90%	Boiling	...	Good	...	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	Plus 10% H_2O	...	Boiling	...	Resistant	...	253
F51	S31803	...	Pure	...	Boiling	...	Resistant	...	253
F51	S31803	...	Raw	90%	Boiling	...	Resistant	...	253



LIVE GRAPH
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Aluminum. Effect of temperature of phenol. Rapid reaction above 120 °C (250 °F) can be stopped by small additions of steam or water. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 608.

Phosgene

Phosgene, $COCL_2$, also known as carbonyl chloride and chloroformyl chloride, is a colorless, poisonous gas produced by the action of chlorine and carbon monoxide. It condenses at 0 °C (32 °F) to a fuming liquid. Phosgene was used as a war gas, but is now used in the production of metal chlorides, pharmaceuticals, isocyanate resins, and perfumes.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Gold. Gold is resistant to phosgene at room temperature.

Corrosion Behavior of Various Metals and Alloys in Phosgene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	...	...	...	...	Resistant	...	92
Miscellaneous									
Gold	P00016	...	...	...	Room	...	0.05 (2) max	...	8

Phosphoric Acid

The term "phosphoric acid" is normally used in reference to orthophosphoric acid (H_3PO_4). In anhydrous form, orthophosphoric acid is a white, crystalline solid that melts at 42.35 °C and forms a hemihydrate ($2H_3PO_4{\cdot}H_2O$) that melts at 29.32 °C. This acid can be produced in virtually any desired concentration, but usually it is supplied as a solution containing from 75 to 85% phosphoric acid and melting at temperatures from 17.5 to 21.1 °C.

Phosphoric acid is obtained by two different means. The wet-process acid is obtained by reacting phosphate rock with concentrated sulfuric acid and concentrating the resulting dilute acid by evaporation. The furnace acid is obtained by calcining the phosphate rock to produce elemental phosphorus, which is then oxidized and reacted with water to produce phosphoric acid. This latter acid is very pure and is used as reagent grade.

The wet-process acid is used to make phosphatic fertilizers and usually contains a number of impurities, such as HF, sulfuric acid, and SiO_2. The percentage of these impurities depends on the source of the rock, the process of reaction with sulfuric acid, and the state of concentration of the phosphoric acid.

Particularly sensitive to the impurities in wet-process acid are the stainless steels, which are widely employed in phosphoric acid service. In addition, a given alloy can corrode at different rates in wet-process acids from different manufacturers. Because of these differences, it is imperative that any comparison between alloys in this type of acid be made from tests conducted in the same batch of acid from the same source. It can also be seen that the wet-process acid can be considerably more corrosive than the reagent grade acid.

When heated to temperatures above 200 °C (390 °F), phosphoric acid loses its water of constitution, and salts of the resulting dehydrated acids are used in preparing some liquid fertilizers and some detergents. Use of these salts in detergents, however, has been severely restricted in an attempt to reduce pollution by phosphates. Phosphoric acid is also used in soft drinks and flavored syrups, in pharmaceuticals, in water treatment, in animal feeds, and for pickling of rustproof metals.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. All cast irons find some application in phosphoric acid, but the presence of contaminants must be carefully evaluated before select-

ing a material for this service. Unalloyed cast irons finds little use in phosphoric acid, with the exception of concentrated acids. Even in concentrated acids, use may be severely limited by the presence of fluorides, chlorides, or sulfuric acid.

High-nickel cast irons find some application in phosphoric acid at and slightly above room temperature. These cast irons can be used over the entire phosphoric acid concentration range. Impurities in the acid may greatly restrict the applicability of this grade of cast iron.

High-chromium cast irons exhibit low rates of attack in phosphoric acid up to 60% concentration. High-silicon cast irons show good-to-excellent resistance at all concentrations and temperatures of pure acid. The presence of fluoride ions (F^-) in phosphoric acid makes the high-silicon irons unacceptable for use.

Stainless Steels. Conventional straight-chromium stainless steels have very limited general corrosion resistance in phosphoric acid and exhibit lower rates only in very dilute or more highly concentrated solutions. Conventional austenitic stainless steels provide useful general corrosion resistance over the full range of concentrations up to about 65 °C (150 °F); use at temperatures up to the boiling point is possible for acid concentrations up to about 40%.

In commercial applications, however, wet-process phosphoric acid environments include impurities derived from the phosphate rock, such as chlorides, fluorides, and sulfuric acid. These three impurities accelerate corrosion, particularly pitting or crevice corrosion in the presence of the halogens. Higher alloyed materials than the conventional austenitic stainless steels are required to resist wet-process phosphoric acid. Candidate materials include alloy 904L, alloy 28, 20Cb-3, 20Mo-4, and 20Mo-6 stainless steels.

Cemented Carbides. The only cemented carbides that are subject to relatively rapid attack by phosphoric acid are the WC-Co compositions. The resistance of cemented TiC to corrosion by phosphoric acid is excellent, being somewhat better than that of cemented WC in hydrochloric and sulfuric acids.

Aluminum. In laboratory tests, aqueous solutions of phosphoric acid (5 to 85%) were corrosive to alloy 1100 and the corrosion rate increased with concentration at ambient temperature. The rate of attack was ~100 mils/yr at 5% and ~1200 mils/yr at 85% concentration. The action of phosphoric acid can be reduced by the addition of inhibitors. Aqueous solutions containing phosphoric acid and chromium trioxide have been used as cleaning solutions and as surface preparation for painting of aluminum alloys.

Copper. In general, copper and copper alloys provide satisfactory service in handling pure phosphoric acid solutions in various concentrations. The acid concentration seems to have less effect on the corrosion rate than the amount of impurities. The impure phosphoric acid produced by the sulfuric acid process may contain a markedly higher concentration of various ions than acid produced by the electric furnace process. These ions increase the corrosion rate up to 150 times, which limits the service lives of copper alloys.

Pure phosphoric acid produced by the electric furnace process contains only small quantities of impurities and is therefore only slightly corrosive to copper and its alloys. Inhibited admiralty metals C44300, C44400, and C44500 are suggested for solutions of pure phosphoric acid.

Accumulation of corrosion products on metal surfaces may also increase both the rate of corrosion and the possibility of pitting. Low-copper alloys, such as C46400 (naval brass), appear to form thin, adherent films of corrosion products. Copper, copper-silicon alloys, and other high-copper alloys form more voluminous, porous films or scales beneath which roughened or pitted surfaces are likely to be found.

The phosphoric acid vapors that condense in electrostatic precipitators at about 120 °C (250 °F) are noticeably more corrosive than solutions of pure phosphoric acid at the same or lower temperatures. The corrosion rates encountered in precipitators are so high that copper alloy wires will not give satisfactory service as electrodes. The high rate of corrosion is probably caused by an abundant supply of oxygen.

Although the corrosion rates of copper cooling tubes in phosphoric acid condensation chambers are high (about 10 mm/yr, or 400 mils/yr), the rates are lower than those of some other materials. Therefore, the use of copper tubes is feasible for this application.

Copper and copper alloys are used in heat-exchanger tubes, pipes, and fittings for handling phosphoric acid, although the corrosion rates of some of these alloys may be comparatively high. Laboratory tests were performed on groups of copper alloys in aerated and unaerated acid, with specimens at the water line, in quiet immersion, and totally submerged. Acid concentrations ranged from 5 to 90%, and temperatures ranged from 20 to 85 °C (70 to 185 °F) except for the copper-aluminum-silicon alloy, which was tested only in 6.5% phosphoric acid at 20 °C (70 °F) with specimens at the water line and in quiet immersion. Corrosion rates for alloy groups were as follows:

- Copper: 22 to 148 mils/yr
- Copper-zinc (70% Cu min): 5 to 280 mils/yr
- Copper-tin: 1 to 52 mils/yr
- Copper-nickel: 1 to 25 mils/yr
- Copper-silicon: 5 to 37 mils/yr
- Copper-aluminum-iron: 5 to 10 mils/yr
- Copper-aluminum-silicon: 11 to 97 mils/yr

Aluminum bronzes are generally suitable for service in phosphoric acid.

Lead. Lead has high corrosion resistance to phosphoric acid, as well as to chromic, sulfuric, and sulfurous acids, and is widely used in their manufacture and handling. It exhibits excellent corrosion resistance to higher concentrations of these acids at elevated temperatures.

Lead finds especially wide application in the manufacture of phosphoric acid from phosphate rock when sulfuric acid is used in the process. Corrosion rates are low for all acid concentrations up to 85%. The corrosion rate of 6% antimonial lead has been reported to be lower than that of chemical lead in a plant test using a solution containing 32% phosphoric acid, 0.4% sulfuric acid, and 1% chlorides at 88 °C (190 °F). In pure acid manufactured from elemental phosphor, lead corrodes at a higher rate because of the absence of sulfates.

Nickel. Nickel alloys that are suitable for handling various concentrations of phosphoric acid include 20Cb-3 and alloys 825, C, G-3, G-30, and 625. Plant test results have shown that 20Cb-3 and alloys 825 and C have the highest corrosion resistance in dilute phosphoric acid process solutions. In very high-concentration phosphoric acid at high temperatures, alloy B-2 exhibits the highest resistance. The corrosion resistance in these acids seems to depend on molybdenum content.

It has been shown that in wet-process phosphoric acid, as opposed to furnace (reagent grade) acid, a high chromium content, such as in alloy G-30, improves corrosion resistance. In addition, Cl^- is inevitably pre-

sent in these acids, and therefore, molybdenum and tungsten additions are beneficial.

Niobium. Niobium is resistant to phosphoric acid at all concentrations and at temperatures below 100 °C (212 °F). In boiling 40 and 50% phosphoric acid with small amounts of F^- impurity (5 ppm), niobium has a corrosion rate of 0.25 mm/yr (10 mils/yr).

Silver. Silver can be used for handling phosphoric acid in all concentrations at temperatures from 160 to 200 °C (320 to 390 °F).

Tantalum. Tantalum exhibits superior resistance to boiling phosphoric acid at all concentrations. At a temperature in excess of boiling, the superiority of tantalum is evident. However, if the phosphoric acid contains more than a few parts per million of F^- ion, as is frequently the case with commercial acid, corrosive attack may occur.

In one study, the corrosion resistance of commercially pure tantalum to a mixture of phosphoric acid, potassium chloride, and water initially containing 60 to 260 ppm F^- was evaluated at 120 °C (250 °F) and at atmospheric pressure. Corrosion rates calculated from the test data were on the order of 0.0005 to 0.15 mm/yr (0.02 to 6 mils/yr), indicating good corrosion resistance.

Zirconium. Zirconium resists attack in phosphoric acid at concentrations up to 55% and at temperatures exceeding the boiling point. Above 55% phosphoric acid, the corrosion rate could increase greatly with temperature. The most interesting area of application of zirconium to phosphoric acid service is in dilute phosphoric acid at elevated temperatures. Tests have shown that zirconium outperforms some stainless alloys in 20% phosphoric acid at 150 °C (300 °F).

Anodic polarization curves for zirconium in phosphoric acid at near-boiling temperatures show that as concentration increases, the passive range diminishes gradually, and the passive current increases progressively. It appears that zirconium passivates more slowly in phosphoric acid than in other mineral acids.

If phosphoric acid contains more than a trace of F^- ion, attack on zirconium may occur. Because fluoride compounds are usually present in phosphoric acid, the use of zirconium has always been questioned. However, because P_2O_5 is an effective fluoride inhibitor for zirconium and a large amount of P_2O_5 is often present in phosphoric acid processes, tests should be performed to determine the suitability of zirconium in the actual phosphoric acid medium.

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
16Ni, 8Cr, 5Si, 1Cu	...	...	...	86	80	96 h	2.7 (108)	...	206
16Ni, 8Cr, 5Si, 1Cu, 1Mo	...	...	...	86	80	96 h	0.03 (1.0)	...	206
Carbon steel	G10100	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	2460 (96800)	...	242
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
70-30 cupronickel	C71500	...	84% P_2O_5. Aerated. Lab tests	116	60 (140)	...	0.03 (1.0)	...	156
70-30 cupronickel	C71500	...	84% P_2O_5. Aerated. Lab tests	116	120 (248)	...	0.29 (11)	...	156
70-30 cupronickel	C71500	...	84% P_2O_5. Aerated. Lab tests	116	180 (356)	...	2.0 (80)	...	156
70-30 cupronickel	C71500	...	84% P_2O_5. Not aerated. Lab tests	116	60 (140)	...	0.003 (0.1)	...	156
70-30 cupronickel	C71500	...	84% P_2O_5. Not aerated. Lab tests	116	120 (248)	...	0.05 (2.0)	...	156
70-30 cupronickel	C71500	...	84% P_2O_5. Not aerated. Lab tests	116	180 (356)	...	0.67 (26)	...	156
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	8.1 (318)	...	242
Aluminumbronze	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	1.14 (45)	...	242
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Copper	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	1.12 (44)	...	242
Copper	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	2.8 (110)	...	242

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper	...	...	Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	3.7 (148) max	...	153
Copper-aluminum-iron	C61300	...	Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	0.25 (10) max	...	153
Copper-aluminum-silicon	C62400	...	Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	6.5	20 (70)	...	2.4 (97) max	...	153
Copper-nickel	...	...	Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	0.63 (25) max	...	153
Copper-silicon	C65500	...	Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	0.93 (37) max	...	153
Copper-tin	C90700	...	Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	1.30 (52) max	...	153
Copper-zinc	...	...	(70% Cu minimum). Totally submerged. Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	5-90	20-85 (70-185)	...	7.0 (280) max	...	153
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	Tests in aerated and unaerated H_3PO_4. Specimens at water line, in quiet immersion	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Irons and alloys									
Ductile austenitic cast iron, type D2	F43000	...	Not aerated	5	50 (122)	6 d	3.9 (154)	...	156
Ductile Ni-Resist type D2	F43000	...	Aerated	85	30 (86)	12 d	6 (240)	...	156
Ni-Resist type1	F41000	...	Aerated	5	30 (86)	1 d	2.8 (112)	...	156
Ni-Resist type1	F41000	...	Aerated	5	30 (86)	1 d	3.1 (124)	...	156
Ni-Resist type1	F41000	...	Aerated	5	87 (190)	0.88 d	9.2 (365)	...	156
Ni-Resist type1	F41000	...	Aerated	15	30 (86)	0.83 d	2.1 (84)	...	156
Ni-Resist type1	F41000	...	Aerated	15	87 (190)	0.83 d	13 (490)	...	156
Ni-Resist type1	F41000	...	Aerated	25	30 (86)	1 d	1.8 (72)	...	156
Ni-Resist type1	F41000	...	Aerated	25	87 (190)	0.83 d	13 (512)	...	156
Ni-Resist type1	F41000	...	Aerated	25	87 (190)	0.83 d	26 (1023)	...	156
Ni-Resist type1	F41000	...	Not aerated	5	30 (86)	1 d	1.7 (66)	...	156
Ni-Resist type1	F41000	...	Not aerated	5	30 (86)	1 d	2.2 (90)	...	156
Ni-Resist type1	F41000	...	Not aerated	5	87 (190)	0.88 d	6.9 (275)	...	156
Ni-Resist type1	F41000	...	Not aerated	15	30 (86)	0.83 d	1.3 (52)	...	156
Ni-Resist type1	F41000	...	Not aerated	15	87 (190)	0.83 d	8.1 (319)	...	156
Ni-Resist type1	F41000	...	Not aerated	25	30 (86)	1 d	1.1 (43)	...	156

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ni-Resist type 1	F41000	...	Not aerated	25	87 (190)	0.83 d	13 (510)	...	156
Ni-Resist type 1	F41000	...	Not aerated	25	87 (190)	0.83 d	19 (757)	...	156
Ni-Resist type 2	F41002	...	Aerated	5	50 (122)	6 d	46 (1810)	...	156
Ni-Resist type 2	F41002	...	Aerated	85	30 (86)	1 d	5.1 (204)	...	156
Ni-Resist type 2	F41002	...	Aerated	85	50 (122)	1 d	22 (860)	...	156
Ni-Resist type 2	F41002	...	Aerated	85	80 (176)	0.25 d	68 (2660)	...	156
Ni-Resist type 2	F41002	...	Aerated	85	30 (86)	12 d	2.2 (87)	...	156
Ni-Resist type 2	F41002	...	Not aerated	5	50 (122)	6 d	24 (960)	...	156
Ni-Resist type 2	F41002	...	Not aerated	85	30 (86)	1 d	5 (199)	...	156
Ni-Resist type D2	F43000	...	Aerated	5	50 (122)	6 d	32 (1260)	...	156
Miscellaneous									
Chemical lead	L51120	...	Commercial	20	21 (70)	...	.09 (3.4)	...	254
Chemical lead	L51120	...	Commercial	30	21 (70)	...	.12 (4.9)	...	254
Chemical lead	L51120	...	Commercial	40	21 (70)	...	.14 (5.7)	...	254
Chemical lead	L51120	...	Commercial	50	21 (70)	...	.16 (6.4)	...	254
Chemical lead	L51120	...	Commercial	85	21 (70)	...	.04 (1.6)	...	254
Chemical lead	L51120	...	Pure	80	21 (70)	...	.32 (12.8)	...	254
Iridium	...	...	...	...	100 (212)	...	Resistant	...	29
Lead	L50045	...	...	...	24-93 (75-200)	...	0.5 (20) max	...	95
Lead	L50045	...	...	20	21 (70)	...	0.09 (3.4)	...	154
Lead	L50045	...	...	30	21 (70)	...	0.12 (4.9)	...	154
Lead	L50045	...	...	40	21 (70)	...	0.14 (5.7)	...	154
Lead	L50045	...	...	50	21 (70)	...	0.16 (6.4)	...	154
Lead	L50045	...	...	85	21 (70)	...	0.04 (1.6)	...	154
Lead	L50045	...	Pure grade	80	21 (70)	...	0.33 (12.8)	...	154
Magnesium	...	...	...	All	Room	...	Poor	...	119
Molybdenum	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	.003 (0.01) max	...	242
Molybdenum	...	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	8 (0.20)	...	242
Osmium	...	...	...	Concentrated	100 (212)	...	Resistant	...	17
Palladium	P03980	...	...	100 g/L	100 (212)	...	0.25 (10) max	...	17
Platinum	P04995	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	0.01 (.003) max	...	242
Platinum	P04995	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	0.05 (2)	...	242
Rhodium	P05990	...	...	100 g/L	100 (212)	...	Resistant	...	29
Silver	P07010	...	...	5	102 (215)	...	0.003 (0.1)	...	4
Silver	P07010	...	...	45	60 (14)	...	Resistant	...	4
Silver	P07010	...	...	45	110 (230)	...	0.007 (0.3)	...	4
Silver	P07010	...	...	67	60 (140)	...	0.004 (0.2)	...	4
Silver	P07010	...	...	67	125 (255)	...	0.02 (0.1)	...	4
Silver	P07010	...	...	85	60 (140)	...	0.002 (0.1)	...	4
Silver	P07010	...	...	85	140 (285)	...	0.048 (1.9)	...	4
Silver	P07010	...	...	85	160 (320)	...	0.306 (12)	...	4
Silver	P07010	...	...	5	102 (215)	...	0.003 (0.1)	...	4
Silver	P07010	...	...	45	60 (140)	...	Resistant	...	4
Silver	P07010	...	...	45	110 (230)	...	0.007 (0.3)	...	4
Silver	P07010	...	...	67	60 (140)	...	0.004 (0.2)	...	4
Silver	P07010	...	...	67	125 (255)	...	0.02 (0.8)	...	4
Silver	P07010	...	...	85	60 (140)	...	0.003 (0.1) max	...	4
Silver	P07010	...	...	85	140 (285)	...	0.05 (1.9)	...	4
Silver	P07010	...	...	85	160 (320)	...	0.31 (12)	...	4

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Silver	P07010	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	0.41 (16)	...	242
Silver	P07010	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	1.27 (50)	...	242
Tin	...	...	...	25	20 (68)	...	Poor	...	94
Tin	...	...	...	25	60 (140)	...	Poor	...	94
Tin	...	...	...	25	100 (212)	...	Poor	...	94
Tin	...	...	...	50	20 (68)	...	Poor	...	94
Tin	...	...	...	50	60 (140)	...	Poor	...	94
Tin	...	...	...	50	100 (212)	...	Poor	...	94
Tin	...	...	...	95	20 (68)	...	Poor	...	94
Tin	...	...	...	95	60 (140)	...	Poor	...	94
Tin	...	...	...	95	100 (212)	...	Poor	...	94
Nickel and alloys									
Alloy 600	N06600	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	104 (4100)	...	242
Alloy 625	N06625	...	...	...	116	...	0.45 (18)	...	212
Alloy 625	N06625	...	...	46	116 (240)	...	0.45 (18)	...	225
Alloy 625	N06625	...	Maximum corrosion rate	70	204	96 h	0.55 (22)	...	212
Alloy 625	N06625	...	Maximum corrosion rate	54	116	96 h	0.90 (36)	...	212
Alloy 625	N06625	...	Maximum corrosion rate	54	149	96 h	20 (803)	...	212
Alloy 625	N06625	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	25 (993)	...	242
Alloy 625	N06625	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	61 (2380)	...	242
Alloy 690	N06690	...	...	...	116	...	0.13 (5)	...	212
Alloy 690	N06690	...	...	52	149 (300)	...	11.2 (447)	...	212
Alloy 690	N06690	...	...	46	116 (240)	...	0.13 (5)	...	225
Alloy 690	N06690	...	...	52	149 (300)	...	3.68 (147)	...	225
Alloy 800	N08800	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	75 (2970)	...	242
Alloy 825	N08825	...	Maximum corrosion rate	54	116	96 h	13.8 (553)	...	212
Alloy 825	N08825	...	Maximum corrosion rate	54	149	96 h	33 (1331)	...	212
Alloy 825	N08825	...	Maximum corrosion rate	70	204	96 h	0.45 (18)	...	212
Alloy 825	N08825	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	36 (1430)	...	242
Alloy B-2	N10665	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	0.18 (7)	...	242
Alloy B-2	N10665	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	0.53 (21)	...	242
Alloy C-276	N10276	...	...	46	116 (241)	...	1.1 (44)	...	212
Alloy C-276	N10276	...	...	46	116 (240)	...	1.10 (44)	...	225
Alloy C-276	N10276	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	6.4 (250)	...	242
Alloy C-276	N10276	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	8.6 (339)	...	242
Alloy G	N06007	...	...	...	116	...	0.40 (16)	...	212
Alloy G	N06007	...	...	46	116 (240)	...	0.40 (16)	...	225
Alloy G	N06007	...	Maximum corrosion rate	54	116	96 h	2.35 (94)	...	212
Alloy G	N06007	...	Maximum corrosion rate	54	149	96 h	43 (1700)	...	212
Alloy G	N06007	...	Maximum corrosion rate	70	204	96 h	0.40 (16)	...	212
Alloy G	N06007	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	39 (1550)	...	242
Alloy G-3	N06985	...	Maximum corrosion rate	54	116	96 h	1.03 (41)	...	212
Alloy G-3	N06985	...	Maximum corrosion rate	54	149	96 h	31 (1246)	...	212
Alloy G-3	N06985	...	Maximum corrosion rate	70	204	96 h	0.70 (28)	...	212

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy G-30	N06030	...	...	...	116	...	0.10 (4)	...	212
Alloy G-30	N06030	...	...	...	149	...	1.53 (61)	...	212
Alloy G-30	N06030	...	...	54	149	...	0.95 (38)	...	212
Alloy G-30	N06030	Welded	...	53	65 (150)	28 d	0.005 (0.2)	...	212
Alloy G-30	N06030	Welded	...	53	93 (200)	28 d	0.03 (1)	...	212
Alloy G-30	N06030	Welded	...	98	132 (270)	28 d	0.25 (10)	...	212
Alloy G-30	N06030	...	Maximum corrosion rate	54	116	96 h	0.18 (7)	...	212
Alloy G-30	N06030	...	Maximum corrosion rate	54	149	96 h	7.93 (317)	...	212
Alloy G-30	N06030	...	Maximum corrosion rate	70	204	96 h	0.25 (10)	...	212
Alloy K-500	N05500	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	4.7 (183)	...	242
Cabot alloy No.625	N06625	...	...	70	116 (240)	96 h	0.30 (12)	...	67
Cabot alloy No.625	N06625	...	...	70	149 (300)	96 h	0.28 (11)	...	67
Cabot alloy No.625	N06625	...	Average of four 24-h periods	55	Boiling	24 h	0.16 (6.3)	...	67
Cabot alloy No.625	N06625	...	Average of four 24-h periods	85	Boiling	24 h	1.7 (67)	...	67
Carpenter Pyromet Alloy 102	...	...	Plus 2% HF. Annealed	25	...	48 h	0.102 (4.08)	...	30
Carpenter Pyromet Alloy 102	...	...	Plus 2% HF. Stress relieved at 843°C (1550°F) for 30 min, furnace cooled	25	...	48 h	0.102 (4.08)	...	30
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	10	Room	...	0.007 (0.3)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	30	Room	...	0.007 (0.3)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	50	Room	...	0.002 (0.1)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	85	Room	...	Resistant	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	10	65 (150)	...	0.05 (2)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	30	65 (150)	...	0.02 (0.8)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	50	65 (150)	...	0.007 (0.3)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	85	65 (150)	...	0.01 (0.4)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	10	Boiling	...	0.025 (1)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	30	Boiling	...	0.08 (3)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	50	Boiling	...	0.08 (3)	...	156
Hastelloy B	N10001	...	Steady-state data calculated from a minimum of five 24-h test periods	85	Boiling	...	0.71 (28)	...	156
Hastelloy B-2	N10665	...	Chemically pure. Heat treated at 1066°C (1950°F), water quenched	10	Boiling	...	0.05 (2)	...	63
Hastelloy B-2	N10665	...	Chemically pure. Heat treated at 1066°C (1950°F), water quenched	30	Boiling	...	0.08 (3)	...	63

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy B-2	N10665	...	Chemically pure. Heat treated at 1066°C (1950°F), water quenched	50	Boiling	...	0.15 (6)	...	63
Hastelloy B-2	N10665	...	Chemically pure. Heat treated at 1066°C (1950°F), water quenched	85	Boiling	...	0.63 (25)	...	63
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	10	Room	...	0.002 (0.1)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	30	Room	...	0.002 (0.1)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	50	Room	...	0.002 (0.1)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	85	Room	...	Resistant	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	10	65 (150)	...	0.005 (0.2)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	30	65 (150)	...	0.002 (0.1)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	50	65 (150)	...	0.007 (0.3)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	85	65 (150)	...	0.007 (0.3)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	10	Boiling	...	0.015 (0.6)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	30	Boiling	...	0.101 (4)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	50	Boiling	...	0.101 (4)	...	156
Hastelloy C	...	...	Steady-state data calculated from a minimum of five 24-h periods	85	Boiling	...	1.14 (45)	...	156
Hastelloy C-4	N06455	...	Determined in lab tests. Aged 100 h at 899°C (1650°F)	85	Boiling	...	2.2 (85)	...	16
Hastelloy C-4	N06455	...	Determined in lab tests. As-welded; gas tungsten arc welded	85	Boiling	...	1.3 (52)	...	16
Hastelloy C-4	N06455	...	Unwelded; Heat treated at 1066°C (1950°F), water quenched	85	Boiling	...	1.5 (61)	...	16
Hastelloy F	N06001	...	...	60	Boiling	20 h	2.5 (97)	...	156
Hastelloy F	N06001	...	...	70	Boiling	20 h	1.9 (73)	...	156
Hastelloy F	N06001	...	...	85	Boiling	20 h	30 (1200)	...	156
Hastelloy F	N06001	...	CP grade. Three 24-h periods	85	160 (320)	24 h	7.3 (287)	...	156,164
Hastelloy G	N06007	...	...	30	102 (215)	...	0.10 (4)	...	156,165
Hastelloy G	N06007	...	...	85	157 (316)	...	0.51 (20)	...	156,165
Hastelloy G	N06007	...	Lab tests. Reagent grade concentrated	85	Boiling	144 h	0.66 (26)	...	145
Hastelloy G	N06007	...	Lab tests. Wet process acid (68.9% phosphoric acid, 4.15% sulfuric acid, 1.85% iron, 5400 ppm fluorides, 2000 ppm chlorides). Samples activated immediately prior to test	68.9	100 (212)	144 h	0.08 (3)	...	145

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy G	N06007	...	Wet process superphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. First stage	70	160 (320)	87 d	0.16 (6.4)	...	145
Hastelloy G	N06007	...	Wet process superphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. Second stage. Residue formed on surface during exposure. The residue contained 81,000 ppm chlorides, 1500 ppm fluorides	70	188 (370)	87 d	0.38 (15)	...	145
Hastelloy G-30	N06030	...	...	46	116 (240)	...	0.10 (4)	...	225
Hastelloy G-30	N06030	...	...	52	149 (300)	...	1.53 (61)	...	225
Hastelloy G-30	N06030	...	...	54	149 (300)	...	0.95 (38)	...	225
Haynes alloy No.625	N06625	...	...	85	Boiling	...	19 (754)	...	23
Illium 98	...	...	Plus 2.9% H_2SO_4, traces of H_2SiF_6, Al and Fe phosphates. In strong filtrate seal tank	36	43 (110)	90 d	0.01 (0.4)	...	152
Illium 98	...	...	Plus 2.9% H_2SO_4, traces of HF, H_2SiF_6, iron phosphate. Evaporator seal tank	52	40-50 (104-122)	61 d	0.015 (0.6)	...	152
Illium 98	...	...	Plus 2.9% H_2SO_4. Some HF. Suspended $CaSO_4$. Reactor outlet just ahead of filter feed box. Agitation	36	77-84 (170-183)	90 d	0.038 (1.5)	...	152
Illium 98	...	...	Plus 3-4% H_2SO_4, 3-4% $CaSO_4$, trace H_2SiF_6. In sump of evaporator seal tank	69	...	81 d	0.022 (0.9)	...	152
Illium 98	...	...	Plus HF, H_2SiF_6, $CaSO_4$. In evaporator discharge of pump before heat	55	80-85 (175-185)	42 d	0.02 (0.8)	...	152
Illium 98	...	...	Plus small amounts of H_2SO_4 and H_2SiF_6. In slurry in reactor. Agitation at 110 ft/min	69	100 (212)	10 d	0.35 (14)	...	152
Illium 98	...	...	Spray. Plus H_2SiF_6, SiF_4, HF, phosphate rock, $CASO_4$. Attached to top of baffle in reactor. Considerable agitation	69	65-85 (149-185)	10 d	0.38 (15)	...	152
Illium G	...	...	Filtered. Small concentration of H_2SO_4 and H_2SiF_6. In filtrate seal tank	61	80 (176)	10 d	0.15 (6)	...	152
Illium G	...	...	Plus 2.9% H_2SO_4, traces of H_2SiF_6, Al and Fe phosphates. In strong filtrate seal tank	36	43 (110)	90 d	0.67 (2.6)	...	152
Illium G	...	...	Plus 2.9% H_2SO_4, traces of HF, H_2SiF_6, iron phosphate. Evaporator seal tank	52	40-50 (104-122)	61 d	0.04 (1.4)	...	152
Illium G	...	...	Plus 2.9% H_2SO_4. Some HF. Suspended $CaSO_4$. Reactor outlet just ahead of filter feed box. Agitation	36	77-84 (170-183)	90 d	0.10 (4)	...	152
Illium G	...	...	Plus 3-4% H_2SO_4, 3-4% $CaSO_4$, trace H_2SiF_6. In sump of evaporator seal tank	69	...	81 d	0.04 (1.4)	...	152
Illium G	...	...	Plus HF, H_2SiF_6, $CaSO_4$. In evaporator discharge of pump before heat	55	80-85 (175-185)	42 d	0.22 (8.7)	...	152
Illium G	...	...	Plus small amounts of H_2SO_4 and H_2SiF_6. In slurry in reactor. Agitation at 110 ft/min	69	100 (212)	10 d	1.9 (72)	...	152

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Illium G	...	...	Spray. Plus H_2SiF_6, SiF_4, HF, phosphate rock, CSO_4. Attached to top of baffle in reactor. Considerable agitation	69	55-85 (149-185)	10 d	0.53 (21)	...	152
Inco alloy G	N06007	...	...	30	Boiling	...	0.10 (4)	...	40
Inco alloy G	N06007	...	...	85	Boiling	...	0.51 (20)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	30	Boiling	7 d	0.08 (3)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	85	Boiling	7 d	0.41 (16)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	85	Boiling	7 d	0.43 (17)	...	40
Incoloy 825	N08825	...	...	60	Boiling	20 h	0.20 (8)	...	156
Incoloy 825	N08825	...	...	70	Boiling	20 h	0.18 (7)	...	156
Incoloy 825	N08825	...	...	85	Boiling	20 h	1.3 (51)	...	156
Incoloy 825	N08825	...	Defluorinator plus 1% H_2SO_4, HF. Violent agitation	75-80	120-157 (250-315)	8 d	3.0 (120)	...	151
Incoloy 825	N08825	...	Evaporator heated with hot gases plus 1-2% H_2SO_4, 1.5% HF, Na_2SiF_6	53	120 (250)	42 d	0.15 (6)	...	151
Incoloy 825	N08825	...	In wet seperator on top of concentrating drum in vapors. Crude, plus HF	To 50-55	107-150 (255-300)	21 d	0.78 (31)	...	151
Incoloy 825	N08825	...	P_2O_5 equivalent 75-77%	104-106	104 (220)	...	0.03 (1.1)	...	156
Incoloy 825	N08825	...	Pitted	78-85	104 (220)	...	0.25 (10)	...	156
Incoloy 825	N08825	...	Plus 2% H_2SO_4, 1% HF, 40% H_2O, $CaSO_4$. Slurry in digestor tank	20	80-93 (170-200)	117 d	0.02 (0.7)	...	151
Incoloy 825	N08825	...	Plus 20% HF in tank	20	21-30 (70-85)	13 d	0.04 (1.4)	...	151
Incoloy 825	N08825	...	Recycle liquor from evaporator fume scrubber. Plus 20% H_2SiF_6, 1% H_2SO_4	15	75-85 (165-185)	16 d	0.025 (1)	...	151
Incoloy 825	N08825	...	Slurry plus 1.6% H_2SO_4, 1.5% H_2SiF_6, 0.12% HF, $CaSO_4$. In filter tank	31.4	46-60 (115-140)	8.3 d	0.002 (0.1) max	...	151
Incoloy 825	N08825	...	Slurry, 27% P_2O_5, in acid transfer tank. Velocity 3 ft/s	37	65-88 (150-190)	46 d	0.02 (0.7)	...	151
Incoloy 825	N08825	...	Thickener in evaporated acid plus 1.7% HF, 2% H_2SO_4, 2% $CaSO_4$	54	52-65 (125-150)	51 d	0.01 (0.5)	...	151
Incoloy 825	N08825	...	Wet process supersphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. Second stage. Residue formed on surface during exposure. The residue contained 81,000 ppm chlorides, 1500 ppm fluorides	70	188 (370)	87 d	0.65 (26)	...	145
Incoloy 825	N08825	...	Wet process supersphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. First stage	70	160 (320)	87 d	0.25 (10)	...	145
Inconel 600	N06600	Solution heat treated sheet	Average. Determined in lab tests. Five 24-h test periods	75	50 (122)	60 d	0.15 (5.9)	...	156,161
Inconel 600	N06600	Solution heat treated sheet	BP 160°C (320°F). Determined in lab tests. Five 24-h test periods	85	Boiling	1 d	270 (14600)	...	156,164
Inconel 600	N06600	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	10	101 (214)	4 d	0.025 (1.0) max	...	156,159
Inconel 600	N06600	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	50	110 (230)	4 d	4.5 (176)	...	156,159
Inconel 600	N06600	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	86	98 (208)	4 d	1.2 (46)	...	156,159

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 600	N06600	Solution heat treated sheet	In tank. Solution circulated. Determined in lab tests. Five 24-h test periods	75	70 (158)	39 d	0.69 (27)	...	156,161
Inconel 600	N06600	Solution heat treated sheet	Solution aerated. Determined in lab tests. Five 24-h test periods	75	75 (167)	2 d	1.3 (52)	...	156,161
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	10	80 (175)	...	0.02 (0.9)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	20	80 (175)	...	0.05 (2)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	30	80 (175)	...	0.03 (1)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	40	80 (175)	...	0.15 (6)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	50	80 (175)	...	0.20 (8)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	60	80 (175)	...	0.15 (6)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	70	80 (175)	...	0.015 (0.6)	...	44
Inconel 617	N06617	...	Plus 1% HF. Pure, lab	85	80 (175)	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	10	80 (175)	...	0.005 (0.2)	...	44
Inconel 617	N06617	...	Pure, lab	10	Boiling	...	0.003 (0.1)	...	44
Inconel 617	N06617	...	Pure, lab	20	80 (175)	...	0.005 (0.2)	...	44
Inconel 617	N06617	...	Pure, lab	20	Boiling	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	30	80 (175)	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	30	Boiling	...	0.013 (0.5)	...	44
Inconel 617	N06617	...	Pure, lab	40	80 (175)	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	40	Boiling	...	0.13 (5)	...	44
Inconel 617	N06617	...	Pure, lab	50	80 (175)	...	0.018 (0.7)	...	44
Inconel 617	N06617	...	Pure, lab	50	Boiling	...	0.79 (31)	...	44
Inconel 617	N06617	...	Pure, lab	60	80 (175)	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	60	Boiling	...	1.27 (50)	...	44
Inconel 617	N06617	...	Pure, lab	70	80 (175)	...	0.010 (0.4)	...	44
Inconel 617	N06617	...	Pure, lab	70	Boiling	...	0.97 (38)	...	44
Inconel 617	N06617	...	Pure, lab	85	80 (175)	...	0.015 (0.6)	...	44
Inconel 617	N06617	...	Pure, lab	85	Boiling	...	0.66 (26)	...	44
Monel 400	N04400	...	...	3.2	25 (77)	49 d	0.041 (1.6)	...	156,161
Monel 400	N04400	...	...	3.2	100 (212)	0.17 d	0.1245 (4.9)	...	156,161
Monel 400	N04400	...	...	10	101 (214)	4 d	0.254 (10)	...	156,159
Monel 400	N04400	...	...	40	27 (80)	5 d	0.025 (1.0)	...	156,161
Monel 400	N04400	...	...	50	110 (230)	4 d	0.1016 (4.0)	...	156,159
Monel 400	N04400	...	...	78-85	25 (77)	...	0.0025 (0.1)	...	156
Monel 400	N04400	...	...	78-85	49 (120)	...	0.025 (1.0)	...	156
Monel 400	N04400	...	...	78-85	104 (220)	...	0.226 (8.9)	...	156
Monel 400	N04400	...	...	90	98 (208)	4 d	0.025 (1.0)	...	156,159
Monel 400	N04400	...	...	85	160 (320)	1	114.935 (4525)	...	156,163
Monel 400	N04400	...	...	117	249-254 (480-490)	...	Poor	...	156,157
Monel 400	N04400	...	Aerated	85	124 (255)	...	11.176 (440)	...	156,157
Monel 400	N04400	...	Aerated	117	60 (140)	6 d	0.254 (10) max	...	156,157
Monel 400	N04400	...	Not aerated	85	124 (255)	6 d	0.254 (10)	...	156,157
Monel 400	N04400	...	Not aerated	117	180 (356)	6 d	0.0838 (3.3)	...	156,157
Monel K-500	N05500	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	517 (13)	...	242
MP35N	R30035	...	...	85	Boiling	...	12.7 (500)	...	23
Nickel 200	N02200	...	84% P_2O_5. Not aerated	116	60 (140)	...	0.330 (13)	...	156
Nickel 200	N02200	...	84% P_2O_5. Not aerated	116	120 (248)	...	58.52 (48)	...	156
Nickel 200	N02200	...	84% P_2O_5. Not aerated	116	180 (356)	...	...	...	156
Nickel 200	N02200	...	Lab tests. 84% P_2O_5	40	27 (80)	5 d	0.025 (1.0)	...	156,161
Nickel 200	N02200	...	Lab tests. 84% P_2O_5	78-85	25 (77)	...	0.0076 (0.3)	...	156
Nickel 200	N02200	...	Lab tests. 84% P_2O_5	78-85	49 (120)	...	0.1067 (4.2)	...	156
Nickel 200	N02200	...	Lab tests. 84% P_2O_5	117	9-254 (48-490)	...	Poor	...	156,157

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	Plant test in mixture of HCl and cresylic acid with phosphorus oxychloride. Test spool at liquid line	...	82 (180)	...	0.425 (17)	...	44
Nickel 200	N02200	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	47 (1830)	...	242
Sanicro 28	N08028	...	Maximum corrosion rate	54	116 (241)	96 h	1.58 (63)	...	212
Sanicro 28	N08028	...	Maximum corrosion rate	54	149 (300)	96 h	81 (3236)	...	212
Sanicro 28	N08028	...	Maximum corrosion rate	70	204 (400)	96 h	1.33 (53)	...	212
Sanicro 28	N08028	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	36 (1400)	...	242
Refractory metals and alloys									
40Co-20Cr-15Ni-7Mo	...	...	...	10	107 (225)	50 h	Resistant	...	54
44Co-31Cr-13W	...	Cast	Based on five 24-h test periods	50	Boiling	...	1.72 (68)	...	53
44Co-31Cr-13W	...	Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	50	Boiling	...	0.55 (22)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	85	65 (150)	...	0.015 (0.6)	...	53
44Co-31Cr-13W	...	Cast	Based on five 24-h test periods	50	Boiling	...	1.7 (68)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	50	Boiling	...	0.55 (22)	...	53
44Co-31Cr-13W	...	Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	85	65 (150)	...	0.02 (0.6)	...	53
50Co-20Cr-15W-10Ni	...	...	...	50	Boiling	...	0.1 (4)	...	53
50Co-20Cr-15W-10Ni	...	...	...	85	65 (150)	...	0.002 (0.1)	...	53
50Co-20Cr-15W-10Ni	...	Cast	Based on five 24-h test periods	50	Boiling	...	0.1 (4)	...	53
50Co-20Cr-15W-10Ni	...	Cast	Based on five 24-h test periods	85	65 (150)	...	0.002 (0.1)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	Cast	Based on five 24-h test periods	50	Boiling	...	0.3 (12)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	50	Boiling	...	0.63 (25)	...	53
53Co-30Cr-4.5W	...	Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
53Co-30Cr-4.5W	...	Cast	Based on five 24-h test periods	50	Boiling	...	0.3 (12)	...	53
53Co-30Cr-4.5W	...	Cast	Based on five 24-h test periods	85	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). Cast	Based on five 24-h test periods	50	Boiling	...	0.63 (25)	...	53
Cobalt	...	...	Static	50	25 (77)	...	0.27 (11)	...	54
Cobalt	...	...	Static	Concentrated	25 (77)	...	0.025 (1)	...	54
Hafnium	...	...	...	60	...	8 d	0.22 (8.5)	...	11
Hafnium	...	...	...	60	...	8 d	0.22 (8.5)	...	11
Havar	R30004	...	...	85	Boiling	...	100 (4000) min	...	23
Haynes alloy No.188	R30188	...	...	85	Boiling	...	13.5 (530)	...	23
Haynes alloy No.21	R30021	...	...	85	Boiling	...	17 (680)	...	23
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	10	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	30	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	50	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	85	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	10	66 (150)	24 h	0.01 (0.1) max	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	30	66 (150)	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	85	Boiling	24 h	14.3 (562)	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	50	66 (150)	24 h	0.01 (0.1) max	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	85	66 (150)	24 h	0.01 (0.1) max	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	10	Boiling	24 h	0.01 (0.2) max	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	30	Boiling	24 h	0.05 (2.0)	...	68
Haynes alloy No.25	R30605	Solution heat treated sheet	Determined in lab tests. Five 24-h test periods	50	Boiling	24 h	0.10 (4.0)	...	68
Haynes alloy No.556	R30556	...	...	85	Boiling	...	0.84 (33)	...	23
Haynes alloy No.6B	...	...	...	85	Boiling	...	16 (610)	...	23
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	10	Room	24 h	Resistant	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	10	66 (150)	24 h	Resistant	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	10	Boiling	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	30	Room	24 h	Resistant	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	30	66 (150)	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	30	Boiling	24 h	0.01 (0.3) max	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	50	Room	24 h	Resistant	...	68

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	50	66 (150)	24 h	0.01 (0.1) max	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	50	Boiling	24 h	0.08 (3.0)	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	85	Room	24 h	Resistant	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	85	66 (150)	24 h	0.003 (0.1) max	...	68
Multimet	R30155	...	Steady-state data calculated from a minimum of five 24-h periods	85	Boiling	24 h	7.70 (303)	...	68
Niobium	R04210	...	...	60	Boiling	...	0.5 (20)	...	2
Niobium	R04210	...	...	85	Room	...	0.003 (0.1)	...	2
Niobium	R04210	...	...	85	88 (190)	...	0.05 (2.0)	...	2
Niobium	R04210	...	...	85	100 (212)	...	0.13 (5.0)	...	2
Niobium	R04210	...	...	85	Boiling	...	3.8 (150)	...	2
Niobium	R04210	...	...	85	19-26 (65-80)	36 d	0.003 (0.1) max	...	74
Niobium	R04210	...	Plus 4% HNO_3	85	88 (190)	...	0.03 (1.0)	...	2
Niobium	R04210	...	Plus 5 ppm F^-	40-50	Boiling	...	0.25 (10)	...	2
Tantalum	R05210	...	...	85	19-26 (65-80)	36 d	Resistant	...	74
Tantalum	R05210	...	...	85	25 (76)	...	Resistant	...	42
Tantalum	R05210	...	...	85	100 (212)	...	Resistant	...	42
Tantalum	R05210	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	0.05 (2)	...	242
Titanium	...	...	...	85	19-26 (65-80)	36 d	0.2 (7)	...	74
Titanium	...	...	...	10-30	Room	...	.02 (0.8)	...	90
Titanium	...	...	...	10-30	Room	...	.05 (2.0)	...	90
Titanium	...	...	...	30-80	Room	...	.05 (.08)	...	90
Titanium	...	...	...	30-80	Room	...	2.0 (30)	...	90
Titanium	...	...	...	5.0	66 (151)	...	0.005 (0.2)	...	90
Titanium	...	...	...	6.0	66 (151)	...	.12 (4.7)	...	90
Titanium	...	...	...	0.5	Boiling	...	.09 (3.8)	...	90
Titanium	...	...	...	1.0	Boiling	...	.27 (11)	...	90
Titanium	...	...	...	12	25 (77)	...	0.005 (0.2)	...	90
Titanium	...	...	...	20	25 (77)	...	.08 (3.0)	...	90
Titanium	...	...	...	50	25 (77)	...	0.19 (7.6)	...	90
Titanium	...	...	...	9	52 (126)	...	0.03 (1.2)	...	90
Titanium	...	...	...	10	52 (126)	...	0.38 (15)	...	90
Titanium	...	...	...	5	Boiling	...	3.5 (140)	...	90
Titanium	...	...	...	10	80 (176)	...	1.83 (73)	...	90
Titanium	...	...	Plus 3% HNO_3	81	88 (190)	...	0.381 (15)	...	90
Titanium, grade 1	R50250	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	1400 (55100)	...	242
Titanium, grade 12	R53400	...	Naturally aerated	25	25 (75)	...	0.02 (0.7)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	30	25 (75)	...	0.06 (2.2)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	45	25 (75)	...	0.16 (6)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	8	52 (125)	...	0.02 (0.8)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	13	52 (125)	...	0.07 (2.6)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	15	52 (125)	...	0.5 (20)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	5	66 (150)	...	0.04 (1.5)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	7	66 (150)	...	0.15 (5.9)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	0.5	Boiling	...	0.07 (2.8)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	1.0	Boiling	...	0.14 (5.5)	...	33

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium, grade 7	R52400	...	Naturally aerated	40	25 (75)	...	0.01 (0.3)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	60	25 (75)	...	0.07 (2.8)	...	333
Titanium, grade 7	R52400	...	Naturally aerated	15	52 (125)	...	0.04 (1.4)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	23	52 (125)	...	0.15 (5.9)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	8	66 (150)	...	0.08 (3.0)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	15	66 (150)	...	0.10 (4.1)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	0.5	Boiling	...	0.05 (2.0)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	1.0	Boiling	...	0.11 (4.2)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	5.0	Boiling	...	0.23 (9)	...	33
Zirconium	R60701	...	Plus 0.5% HNO_3	88	Room	...	Resistant	...	36
Zirconium	R60701	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	655 (25800)	...	242
Zirconium	R60701	...	Tarnished	85	19-26 (65-80)	36 d	0.0005 (0.02)	...	74
Zr702	R60702	...	...	5-30	Room	...	0.13 (5) max	...	15
Zr702	R60702	...	...	5-36	60 (140)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	5-50	100 (212)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	35-50	Room	...	0.13 (5) max	...	15
Zr702	R60702	...	...	45	Boiling	...	0.13 (5) max	...	15
Zr702	R60702	...	...	65	100 (212)	...	0.25 (10) max	...	15
Zr702	R60702	...	...	85	38 (100)	...	0.5 (20) max	...	15
Zr702	R60702	...	...	85	80 (175)	...	1.3 (50) max	...	15
Zr702	R60702	...	BP 108°C (226°F)	50	Boiling	...	0.13 (5) max	...	15
Zr702	R60702	...	BP 123-126°C (253-259°F)	70	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	BP 156°C (313°F)	85	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	Plus 0.5% HNO_3	88	Room	...	Resistant	...	15
Zr702	R60702	...	Plus 4% HNO_3	85	89 (190)	...	1.3 (50) min	...	15
Zr704	R60704	...	BP 108°C (226°F)	50	Boiling	...	0.25 (10) max	...	15
Zr705	R60705	...	...	65	100 (212)	...	0.5 (20) max	...	15
Zr705	R60705	...	...	85	80 (175)	...	1.3 (50) max	...	15
Zr705	R60705	...	BP 108°C (226°F)	50	Boiling	...	0.38 (15) max	...	15
Zr705	R60705	...	BP 123-126°C (253-259°F)	70	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	BP 156°C (313°F)	85	Boiling	...	1.3 (50) min	...	15
Zr705	R60705	...	Plus 4% HNO_3	85	89 (190)	...	13 (50) min	...	15
Stainless steels									
20Cb-3	N08020	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	20 (792)	...	242
26Cr-1Mo	S44627	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	2160 (84900)	...	242
29Cr-4Mo	S44700	...	...	20	Boiling	...	Resistant	...	155
29Cr-4Mo	S44700	...	...	54	Boiling	...	0.03 (1.2)	...	155
29Cr-4Mo	S44700	...	...	60	Boiling	...	0.12 (4.8)	...	155
29Cr-4Mo-2Ni	S44800	...	...	20	Boiling	...	Resistant	...	155
29Cr-4Mo-2Ni	S44800	...	...	54	Boiling	...	0.03 (1.2)	...	155
29Cr-4Mo-2Ni	S44800	...	...	6	Boiling	...	0.12 (4.8)	...	155
301	S30100	...	...	1	20 (68)	...	Resistant	...	253
301	S30100	...	...	1	Boiling	...	Resistant	...	253
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
301	S30100	...	...	45	20 (68)	...	Resistant	...	253
301	S30100	...	...	45	Boiling	...	Questionable	...	253
301	S30100	...	...	60	20 (68)	...	Resistant	...	253
301	S30100	...	...	60	Boiling	...	Questionable	...	253
301	S30100	...	...	70	20 (68)	...	Resistant	...	253
301	S30100	...	...	70	Boiling	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	80	20 (68)	...	Good	...	253
301	S30100	...	...	80	Boiling	...	Poor	...	253
301	S30100	...	...	Concentrated	20 (68)	...	Good	...	253
301	S30100	...	...	Concentrated	Boiling	...	Poor	...	253
301	S30100	...	Dry or moist	...	20 (68)	...	Good	...	253
302	S30200	...	...	1	20 (68)	...	Resistant	...	253
302	S30200	...	...	1	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	45	20 (68)	...	Resistant	...	253
302	S30200	...	...	45	Boiling	...	Questionable	...	253
302	S30200	...	...	60	20 (68)	...	Resistant	...	253
302	S30200	...	...	60	Boiling	...	Questionable	...	253
302	S30200	...	...	70	20 (68)	...	Resistant	...	253
302	S30200	...	...	70	Boiling	...	Questionable	...	253
302	S30200	...	...	80	20 (68)	...	Good	...	253
302	S30200	...	...	80	Boiling	...	Poor	...	253
302	S30200	...	...	Concentrated	20 (68)	...	Good	...	253
302	S30200	...	...	Concentrated	Boiling	...	Poor	...	253
302	S30200	...	Dry or moist	...	20 (68)	...	Good	...	253
303	S30300	...	...	1	20 (68)	...	Resistant	...	253
303	S30300	...	...	1	20 (68)	...	Resistant	...	253
303	S30300	...	...	1	Boiling	...	Good	...	253
303	S30300	...	...	1	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	45	20 (68)	...	Questionable	...	253
303	S30300	...	...	45	20 (68)	...	Resistant	...	253
303	S30300	...	...	45	Boiling	...	Questionable	...	253
303	S30300	...	...	45	Boiling	...	Questionable	...	253
303	S30300	...	...	60	20 (68)	...	Questionable	...	253
303	S30300	...	...	60	20 (68)	...	Resistant	...	253
303	S30300	...	...	60	Boiling	...	Poor	...	253
303	S30300	...	...	60	Boiling	...	Questionable	...	253
303	S30300	...	...	70	20 (68)	...	Questionable	...	253
303	S30300	...	...	70	20 (68)	...	Resistant	...	253
303	S30300	...	...	70	Boiling	...	Poor	...	253
303	S30300	...	...	70	Boiling	...	Questionable	...	253
303	S30300	...	...	80	20 (68)	...	Questionable	...	253
303	S30300	...	...	80	20 (68)	...	Good	...	253
303	S30300	...	...	80	Boiling	...	Poor	...	253
303	S30300	...	...	80	Boiling	...	Poor	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Questionable	...	253
303	S30300	...	...	Concentrated	20 (68)	...	Good	...	253
303	S30300	...	...	Concentrated	Boiling	...	Poor	...	253
303	S30300	...	...	Concentrated	Boiling	...	Poor	...	253
303	S30300	...	Dry or moist	...	20 (68)	...	Good	...	253
304	S30400	...	...	30	50 (122)	...	.23 (9.1)	...	258
304	S30400	...	...	50	50 (122)	...	.046 (1.8)	...	258
304	S30400	...	...	70	50 (122)	...	.38 (15)	...	258
304	S30400	...	...	85	50 (122)	...	.23 (9.1)	...	258

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	30	80 (176)	...	.23 (91)	...	258
304	S30400	...	...	50	80 (176)	...	.092 (3.6)	...	258
304	S30400	...	...	70	80 (176)	...	5.3 (210)	...	258
304	S30400	...	...	85	80 (176)	...	0.69 (27)	...	258
304	S30400	...	...	30	100 (212)	...	.92 (36)	...	258
304	S30400	...	...	50	100 (212)	...	.23 (9.1)	...	258
304	S30400	...	...	70	100 (212)	...	22 (865)	...	258
304	S30400	...	...	85	100 (212)	...	2500 (98000)	...	258
304	S30400	...	...	1	20 (68)	...	Resistant	...	253
304	S30400	...	...	1	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	45	20 (68)	...	Resistant	...	253
304	S30400	...	...	45	Boiling	...	Questionable	...	253
304	S30400	...	...	60	20 (68)	...	Resistant	...	253
304	S30400	...	...	60	Boiling	...	Questionable	...	253
304	S30400	...	...	70	20 (68)	...	Resistant	...	253
304	S30400	...	...	70	Boiling	...	Questionable	...	253
304	S30400	...	...	80	20 (68)	...	Good	...	253
304	S30400	...	...	80	Boiling	...	Poor	...	253
304	S30400	...	...	Concentrated	20 (68)	...	Good	...	253
304	S30400	...	...	Concentrated	Boiling	...	Poor	...	253
304	S30400	...	Aerated	10	21 (70)	...	Good	...	121
304	S30400	...	Air free	10	21 (70)	...	Good	...	121
304	S30400	...	BP 101°C (214°F). Specimens activated before exposure. Not aerated	10	Boiling	0.08 d	Resistant	...	156,158
304	S30400	...	BP 102°C (216°F). Not aerated	25	Boiling	5 d	0.025 (1)	...	156,160
304	S30400	...	BP 116°C (240°F). Not aerated	60	Boiling	0.83 d	...	...	156,161
304	S30400	...	BP 126°C (259°F). Not aerated	70	Boiling	0.83 d	...	...	156,161
304	S30400	...	BP 146°C (294°F). Not aerated	80	Boiling	0.83 d	...	...	156,161
304	S30400	...	Dry or moist	...	20 (68)	...	Good	...	253
304	S30400	...	No activation	50	Boiling	24 h	20 (785)	...	52
304	S30400	...	Not aerated	10	93 (200)	16 d	...	...	156,157
304	S30400	...	Not aerated	10	101 (214)	4 d	0.025 (1) max	...	156,159
304	S30400	...	Not aerated	50	110 (230)	4 d	0.2 (8)	...	156,159
304	S30400	...	Not aerated	76	85 (185)	16 d	...	...	156,162
304	S30400	...	Not aerated	76	100 (212)	16 d	...	...	156,162
304	S30400	...	Not aerated	76	115 (239)	16 d	...	...	156,162
304	S30400	...	Not aerated	78-85	Room	16 d	0.0025 (0.1) max	...	156,157
304	S30400	...	Not aerated	75-85	104 (220)	16 d	5.8 (230)	...	156,157
304	S30400	...	Not aerated	75-85	116 (240)	16 d	...	...	156,157
304	S30400	...	Not aerated	85	85 (185)	16 d	...	...	156,162
304	S30400	...	Not aerated	85	100 (212)	16 d	...	...	156,162
304	S30400	...	Not aerated	85	115 (239)	16 d	...	...	156,162
304	S30400	...	Not aerated	86	98 (208)	4 d	25.4 (1000) min	...	156,159
304	S30400	...	Not aerated	10	101 (214)	4 d	0.025 (1) max	...	156,159
304	S30400	...	Not aerated	50	110 (230)	4 d	0.203 (8)	...	156,159
304	S30400	...	Not aerated	78-85	Room	16 d	0.002 (0.1) max	...	156,157
304	S30400	...	Not aerated	78-85	104 (220)	16 d	5.8 (230)	...	156,157
304	S30400	...	Not aerated	86	98 (208)	4 d	25.4 (1000) min	...	156,159

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Not aerated	25	102 (216)	5 d	0.025 (1)	...	156,160
304	S30400	...	Specimens activated before exposure. Not aerated	10	101 (214)	0.08 d	Resistant	...	156,158
304	S30400	...	With 0.04 mol/L bromide	30	50 (122)	...	.23 (9.1)	...	258
304	S30400	...	With 0.04 mol/L bromide	50	50 (122)	...	.046 (1.8)	...	258
304	S30400	...	With 0.04 mol/L bromide	70	50 (122)	...	.69 (27)	...	258
304	S30400	...	With 0.04 mol/L bromide	85	50 (122)	...	.46 (18)	...	258
304	S30400	...	With 0.04 mol/L bromide	30	80 (176)	...	.23 (9.1)	...	258
304	S30400	...	With 0.04 mol/L bromide	50	80 (176)	...	.092 (3.6)	...	258
304	S30400	...	With 0.04 mol/L bromide	70	80 (176)	...	5.1 (200)	...	258
304	S30400	...	With 0.04 mol/L bromide	85	80 (176)	...	5.5 (217)	...	258
304	S30400	...	With 0.04 mol/L bromide	30	100 (212)	...	.69 (27)	...	258
304	S30400	...	With 0.04 mol/L bromide	50	100 (212)	...	.23 (9.1)	...	258
304	S30400	...	With 0.04 mol/L bromide	70	100 (212)	...	17.5 (690)	...	258
304	S30400	...	With 0.04 mol/L bromide	85	100 (212)	...	12.4 (490)	...	258
304	S30400	...	With 0.04 mol/L chloride	30	50 (122)	...	.23 (9.1)	...	258
304	S30400	...	With 0.04 mol/L chloride	50	50 (122)	...	.046 (1.8)	...	258
304	S30400	...	With 0.04 mol/L chloride	85	50 (122)	...	237 (9300)	...	258
304	S30400	...	With 0.04 mol/L chloride	30	80 (176)	...	.46 (18)	...	258
304	S30400	...	With 0.04 mol/L chloride	50	80 (176)	...	.092 (3.6)	...	258
304	S30400	...	With 0.04 mol/L chloride	70	80 (176)	...	138 (5400)	...	258
304	S30400	...	With 0.04 mol/L chloride	85	80 (176)	...	1438 (57000)	...	258
304	S30400	...	With 0.04 mol/L chloride	30	100 (212)	...	.69 (27)	...	258
304	S30400	...	With 0.04 mol/L chloride	50	100 (212)	...	149 (5900)	...	258
304	S30400	...	With 0.04 mol/L chloride	70	100 (212)	...	539 (21000)	...	258
304	S30400	...	With 0.04 mol/L chloride	85	100 (212)	...	3950 (156000)	...	258
304	S30400	...	With 0.04 mol/L fluoride	30	50 (122)	...	.23 (9.1)	...	258
304	S30400	...	With 0.04 mol/L fluoride	50	50 (122)	...	.046 (1.8)	...	258
304	S30400	...	With 0.04 mol/L fluoride	70	50 (122)	...	9.9 (390)	...	258
304	S30400	...	With 0.04 mol/L fluoride	85	50 (122)	...	2.8 (110)	...	258
304	S30400	...	With 0.04 mol/L fluoride	30	80 (176)	...	3.0 (118)	...	258
304	S30400	...	With 0.04 mol/L fluoride	50	80 (176)	...	11.5 (453)	...	258
304	S30400	...	With 0.04 mol/L fluoride	70	80 (176)	...	10.1 (398)	...	258
304	S30400	...	With 0.04 mol/L fluoride	85	80 (176)	...	979 (38000)	...	258
304	S30400	...	With 0.04 mol/L fluoride	30	100 (212)	...	17 (670)	...	258
304	S30400	...	With 0.04 mol/L fluoride	50	100 (212)	...	62 (2440)	...	258
304	S30400	...	With 0.04 mol/L fluoride	70	100 (212)	...	45 (1773)	...	258
304	S30400	...	With 0.04 mol/L fluoride	85	100 (212)	...	2553 (100000)	...	258
304	S30400	...	With 0.04 mol/L fluoride	70	50 (122)	...	31 (1220)	...	258
304L	S30403	...	...	1	20 (68)	...	Resistant	...	253
304L	S30403	...	...	1	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	45	20 (68)	...	Resistant	...	253
304L	S30403	...	...	45	Boiling	...	Questionable	...	253
304L	S30403	...	...	60	20 (68)	...	Resistant	...	253
304L	S30403	...	...	60	Boiling	...	Questionable	...	253
304L	S30403	...	...	70	20 (68)	...	Resistant	...	253
304L	S30403	...	...	70	Boiling	...	Questionable	...	253
304L	S30403	...	...	80	20 (68)	...	Good	...	253
304L	S30403	...	...	80	Boiling	...	Poor	...	253
304L	S30403	...	...	Concentrated	20 (68)	...	Good	...	253
304L	S30403	...	...	Concentrated	Boiling	...	Poor	...	253
304L	S30403	...	Dry or moist	...	20 (68)	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	1	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	1	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	45	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	45	Boiling	...	Questionable	...	253
304LN	S30453	...	...	60	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	60	Boiling	...	Questionable	...	253
304LN	S30453	...	...	70	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	70	Boiling	...	Questionable	...	253
304LN	S30453	...	...	80	20 (68)	...	Good	...	253
304LN	S30453	...	...	80	Boiling	...	Poor	...	253
304LN	S30453	...	...	Concentrated	20 (68)	...	Good	...	253
304LN	S30453	...	...	Concentrated	Boiling	...	Poor	...	253
304LN	S30453	...	Dry or moist	...	20 (68)	...	Good	...	253
316	S31600	...	...	10	101 (214)	96 h	0.025 (1) max	...	156
316	S31600	...	...	20	Boiling	...	0.18 (7.2)	...	155
316	S31600	...	...	50	110 (230)	96 h	0.15 (6)	...	156
316	S31600	...	...	54	Boiling	...	0.6 (22)	...	155
316	S31600	...	...	60	Boiling	...	0.6 (22)	...	155
316	S31600	...	...	75-85	104 (220)	...	0.13 (5)	...	156
316	S31600	...	...	86	97 (208)	96 h	0.4 (16)	...	156
316	S31600	...	...	30	50 (122)	...	.0045 (.18)	...	257
316	S31600	...	...	50	50 (122)	...	.0045 (.18)	...	257
316	S31600	...	...	70	50 (122)	...	.023 (.91)	...	257
316	S31600	...	...	85	50 (122)	...	.023 (.91)	...	257
316	S31600	...	...	30	80 (176)	...	.009 (.36)	...	257
316	S31600	...	...	50	80 (176)	...	.023 (.91)	...	257
316	S31600	...	...	70	80 (176)	...	.090 (3.6)	...	257
316	S31600	...	...	85	80 (176)	...	.54 (21.6)	...	257
316	S31600	...	...	30	100 (212)	...	.40 (16)	...	257
316	S31600	...	...	50	100 (212)	...	1.03 (41)	...	257
316	S31600	...	...	70	100 (212)	...	1.75 (70)	...	257
316	S31600	...	...	85	100 (212)	...	.43 (17)	...	257
316	S31600	...	...	30	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	...	50	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	...	70	50 (122)	...	.092 (3.6)	...	258
316	S31600	...	...	85	50 (122)	...	.092 (3.6)	...	258
316	S31600	...	...	1	20 (68)	...	Resistant	...	253
316	S31600	...	...	1	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	45	20 (68)	...	Resistant	...	253
316	S31600	...	...	45	Boiling	...	Good	...	253
316	S31600	...	...	60	20 (68)	...	Resistant	...	253
316	S31600	...	...	60	Boiling	...	Good	...	253
316	S31600	...	...	70	20 (68)	...	Resistant	...	253
316	S31600	...	...	70	Boiling	...	Questionable	...	253
316	S31600	...	...	80	20 (68)	...	Resistant	...	253
316	S31600	...	...	80	Boiling	...	Questionable	...	253
316	S31600	...	...	Concentrated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Concentrated	Boiling	...	Poor	...	253
316	S31600	...	Aerated	10	21 (70)	...	Resistant	...	121

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Aerated	10	93 (200)	16 d	0.005 (0.2)	...	156,157
316	S31600	...	Aerated	76	85 (185)	16 d	Resistant	...	156,162
316	S31600	...	Aerated	76	100 (212)	16 d	0.01 (0.4)	...	156,162
316	S31600	...	Aerated	76	115 (239)	16 d	0.02 (0.7)	...	156,162
316	S31600	...	Aerated	78-85	115 (239)	16 d	0.23 (9.2)	...	156,161
316	S31600	...	Aerated	85	85 (185)	16 d	0.004 (0.2)	...	156,162
316	S31600	...	Aerated	85	100 (212)	16 d	0.009 (0.4)	...	156,162
316	S31600	...	Air free	10	21 (70)	...	Good	...	121
316	S31600	...	BP 101°C (214°F). Specimens activated before exposure. Not aerated	10	Boiling	0.08 d	...	...	156,158
316	S31600	...	BP 102°C (216°F). Not aerated	25	Boiling	5 d	...	...	156,160
316	S31600	...	BP 116°C (240°F). Not aerated	60	Boiling	0.83 d	2.7 (107)	...	156,161
316	S31600	...	BP 116°C (240°F). Not aerated	60	Boiling	0.83 d	...	...	156,161
316	S31600	...	BP 126°C (259°F). Not aerated	70	Boiling	0.83 d	5.4 (212)	...	156,161
316	S31600	...	BP 126°C (259°F). Not aerated	70	Boiling	0.83 d	...	...	156,161
316	S31600	...	BP 146°C (294°F). Not aerated	80	Boiling	0.83 d	...	...	156,161
316	S31600	...	BP 146°C (294°F). Not aerated	80	Boiling	0.83 d	20 (793)	...	156,161
316	S31600	...	Dry or moist	...	20 (68)	...	Resistant	...	253
316	S31600	...	No activation	50	Boiling	24 h	0.19 (7.5)	...	52
316	S31600	...	Not aerated	10	93 (200)	16 d	0.0025 (0.1)	...	156,157
316	S31600	...	Not aerated	10	93 (200)	16 d	0.005 (0.2)	...	156,157
316	S31600	...	Not aerated	10	93 (200)	16 d	0.002 (0.1)	...	156,157
316	S31600	...	Not aerated	10	101 (214)	4 d	0.025 (1) max	...	156,159
316	S31600	...	Not aerated	10	101 (214)	4 d	...	...	156,159
316	S31600	...	Not aerated	10	101 (214)	4 d	0.025 (1) max	...	156,159
316	S31600	...	Not aerated	50	110 (230)	4 d	0.15 (6)	...	156,159
316	S31600	...	Not aerated	50	110 (230)	4 d	...	...	156,159
316	S31600	...	Not aerated	60	115 (240)	0.83 d	2.7 (107)	...	156,161
316	S31600	...	Not aerated	70	126 (259)	0.83 d	5.4 (212)	...	156,161
316	S31600	...	Not aerated	75-85	Room	16 d	0.0025 (0.1) max	...	156,157
316	S31600	...	Not aerated	75-85	Room	16 d	...	...	156,157
316	S31600	...	Not aerated	75-85	104 (220)	16 d	0.13 (5)	...	156,157
316	S31600	...	Not aerated	75-85	104 (220)	16 d	...	...	156,157
316	S31600	...	Not aerated	75-85	116 (240)	16 d	0.23 (9)	...	156,157
316	S31600	...	Not aerated	76	85 (185)	16 d	0.001 (0.1) max	...	156,162
316	S31600	...	Not aerated	76	85 (185)	16 d	0.001 (0.1) max	...	156,162
316	S31600	...	Not aerated	76	85 (185)	16 d	0.00 (0.00)	...	156,162
316	S31600	...	Not aerated	76	100 (212)	16 d	0.04 (1.4)	...	156,162
316	S31600	...	Not aerated	76	100 (212)	16 d	0.01 (0.4)	...	156,162
316	S31600	...	Not aerated	76	100 (212)	16 d	0.04 (1.4)	...	156,162
316	S31600	...	Not aerated	76	115 (239)	16 d	0.17 (6.7)	...	156,162
316	S31600	...	Not aerated	76	115 (239)	16 d	0.02 (0.71)	...	156,162
316	S31600	...	Not aerated	76	115 (239)	16 d	0.17 (6.7)	...	156,162
316	S31600	...	Not aerated	78-85	Room	16 d	0.002 (0.1)	...	156,157
316	S31600	...	Not aerated	78-85	104 (220)	16 d	0.127 (5)	...	156,157
316	S31600	...	Not aerated	80	145 (294)	0.83 d	20 (793)	...	156,161
316	S31600	...	Not aerated	85	85 (185)	16 d	.004 (0.1)	...	156,162
316	S31600	...	Not aerated	85	85 (185)	16 d	.003 (0.1)	...	156,162

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Not aerated	85	85 (185)	16 d	.004 (0.2)	...	156,162
316	S31600	...	Not aerated	85	100 (212)	16 d	0.03 (1.2)	...	156,162
316	S31600	...	Not aerated	85	100 (212)	16 d	.03 (1.2)	...	156,162
316	S31600	...	Not aerated	85	100 (212)	16 d	.01 (0.4)	...	156,162
316	S31600	...	Not aerated	85	115 (239)	16 d	0.14 (6)	...	156,162
316	S31600	...	Not aerated	85	115 (239)	16 d	0.02 (0.7)	...	156,162
316	S31600	...	Not aerated	85	115 (239)	16 d	0.13 (5.7)	...	156,162
316	S31600	...	Not aerated	86	97 (208)	4 d	0.4 (16)	...	156,159
316	S31600	...	Not aerated	86	98 (208)	4 d	...	...	156,159
316	S31600	...	Not aerated	86	98 (208)	4 d	0.4 (16)	...	156,159
316	S31600	...	P_2O_5 equivalent 75-77%	104-106	104 (220)	...	0.01 (0.5)	...	156
316	S31600	...	Plus 0.04% Cu. CP grade. Three 24-h periods	85	160 (320)	24 h	42 (1660)	...	156,164
316	S31600	...	Plus 0.32% Cu. CP grade. Three 24-h periods	85	160 (320)	24 h	11 (445)	...	156,164
316	S31600	...	With .04 mol/L fluoride	30	50 (122)	...	.0045 (.18)	...	257
316	S31600	...	With .04 mol/L fluoride	50	50 (122)	...	.0045 (.18)	...	257
316	S31600	...	With .04 mol/L fluoride	70	50 (122)	...	.11 (4.5)	...	257
316	S31600	...	With .04 mol/L fluoride	85	50 (122)	...	.023 (.91)	...	257
316	S31600	...	With .04 mol/L fluoride	30	80 (176)	...	.14 (5.4)	...	257
316	S31600	...	With .04 mol/L fluoride	50	80 (176)	...	.41 (16.2)	...	257
316	S31600	...	With .04 mol/L fluoride	70	80 (176)	...	.36 (14.4)	...	257
316	S31600	...	With .04 mol/L fluoride	85	80 (176)	...	.18 (7.2)	...	257
316	S31600	...	With .04 mol/L fluoride	30	100 (212)	...	1.1 (44)	...	257
316	S31600	...	With .04 mol/L fluoride	50	100 (212)	...	1.39 (55)	...	257
316	S31600	...	With .04 mol/L fluoride	70	100 (212)	...	1.88 (75)	...	257
316	S31600	...	With .04 mol/L fluoride	85	100 (212)	...	3.13 (125)	...	257
316	S31600	...	With 0.04 mol/L bromide	30	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L bromide	50	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L bromide	70	50 (122)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L bromide	85	50 (122)	...	.14 (5.5)	...	258
316	S31600	...	With 0.04 mol/L bromide	30	80 (176)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L bromide	50	80 (176)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L bromide	70	80 (176)	...	1.15 (45)	...	258
316	S31600	...	With 0.04 mol/L bromide	85	80 (176)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L bromide	30	100 (212)	...	1.15 (45)	...	258
316	S31600	...	With 0.04 mol/L bromide	50	100 (212)	...	1.38 (54)	...	258
316	S31600	...	With 0.04 mol/L bromide	70	100 (212)	...	15 (590)	...	258
316	S31600	...	With 0.04 mol/L bromide	85	100 (212)	...	0.46 (18)	...	258
316	S31600	...	With 0.04 mol/L chloride	30	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L chloride	50	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L chloride	70	50 (122)	...	1.15 (45)	...	258
316	S31600	...	With 0.04 mol/L chloride	85	50 (122)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L chloride	30	80 (176)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L chloride	50	80 (176)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L chloride	70	80 (176)	...	5.5 (217)	...	258
316	S31600	...	With 0.04 mol/L chloride	85	80 (176)	...	3.7 (145)	...	258
316	S31600	...	With 0.04 mol/L chloride	30	100 (212)	...	1.4 (55)	...	258
316	S31600	...	With 0.04 mol/L chloride	50	100 (212)	...	2.1 (83)	...	258
316	S31600	...	With 0.04 mol/L chloride	70	100 (212)	...	26 (1025)	...	258
316	S31600	...	With 0.04 mol/L chloride	85	100 (212)	...	12 (470)	...	258
316	S31600	...	With 0.04 mol/L fluoride	30	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L fluoride	50	50 (122)	...	.046 (1.8)	...	258
316	S31600	...	With 0.04 mol/L fluoride	70	50 (122)	...	.23 (9.1)	...	258

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	With 0.04 mol/L fluoride	85	50 (122)	...	.23 (9.1)	...	258
316	S31600	...	With 0.04 mol/L fluoride	30	80 (176)	...	1.4 (55)	...	258
316	S31600	...	With 0.04 mol/L fluoride	50	80 (176)	...	4.2 (165)	...	258
316	S31600	...	With 0.04 mol/L fluoride	70	80 (176)	...	3.7 (146)	...	258
316	S31600	...	With 0.04 mol/L fluoride	85	80 (176)	...	1.8 (71)	...	258
316	S31600	...	With 0.04 mol/L fluoride	30	100 (212)	...	11 (433)	...	258
316	S31600	...	With 0.04 mol/L fluoride	50	100 (212)	...	14 (552)	...	258
316	S31600	...	With 0.04 mol/L fluoride	70	100 (212)	...	19 (750)	...	258
316	S31600	...	With 0.04 mol/L fluoride	85	100 (212)	...	32 (1260)	...	258
316F	S31620	...	...	1	20 (68)	...	Resistant	...	253
316F	S31620	...	...	1	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	45	20 (68)	...	Resistant	...	253
316F	S31620	...	...	45	Boiling	...	Questionable	...	253
316F	S31620	...	...	60	20 (68)	...	Resistant	...	253
316F	S31620	...	...	60	Boiling	...	Questionable	...	253
316F	S31620	...	...	70	20 (68)	...	Resistant	...	253
316F	S31620	...	...	70	Boiling	...	Questionable	...	253
316F	S31620	...	...	80	20 (68)	...	Good	...	253
316F	S31620	...	...	80	Boiling	...	Poor	...	253
316F	S31620	...	...	Concentrated	20 (68)	...	Good	...	253
316F	S31620	...	...	Concentrated	Boiling	...	Poor	...	253
316F	S31620	...	Dry or moist	...	20 (68)	...	Good	...	253
316L	S31603	...	...	60	Boiling	20 h	2.7 (107)	...	156
316L	S31603	...	...	70	Boiling	20 h	5.4 (212)	...	156
316L	S31603	...	...	85	Boiling	20 h	20 (793)	...	156
316L	S31603	Welded	...	53	65 (150)	28 d	0.04 (1.4)	...	212
316L	S31603	Welded	...	53	93 (200)	28 d	0.28 (11)	...	212
316L	S31603	Welded	...	53	132 (270)	28 d	25 (1003)	...	212
316L	S31603	...	...	1	20 (68)	...	Resistant	...	253
316L	S31603	...	...	1	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	45	20 (68)	...	Resistant	...	253
316L	S31603	...	...	45	Boiling	...	Good	...	253
316L	S31603	...	...	60	20 (68)	...	Resistant	...	253
316L	S31603	...	...	60	Boiling	...	Good	...	253
316L	S31603	...	...	70	20 (68)	...	Resistant	...	253
316L	S31603	...	...	70	Boiling	...	Questionable	...	253
316L	S31603	...	...	80	20 (68)	...	Resistant	...	253
316L	S31603	...	...	80	Boiling	...	Questionable	...	253
316L	S31603	...	...	Concentrated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Concentrated	Boiling	...	Poor	...	253
316L	S31603	...	Dry or moist	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	5000 (127)	...	242
316L	S31603	...	Plus 3 ppm chloride and 59 ppm arsenic	75	250 (480)	6 h	391 (15400)	...	242
316LN	S31653	...	...	1	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	1	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	45	20 (68)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	45	Boiling	...	Good	...	253
316LN	S31653	...	...	60	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	60	Boiling	...	Good	...	253
316LN	S31653	...	...	70	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	70	Boiling	...	Questionable	...	253
316LN	S31653	...	...	80	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	80	Boiling	...	Questionable	...	253
316LN	S31653	...	...	Concentrated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Concentrated	Boiling	...	Poor	...	253
316LN	S31653	...	Dry or moist	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	1	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	1	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	45	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	45	Boiling	...	Good	...	253
316Ti	S31635	...	...	60	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	60	Boiling	...	Good	...	253
316Ti	S31635	...	...	70	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	70	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	80	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	80	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	Concentrated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Concentrated	Boiling	...	Poor	...	253
316Ti	S31635	...	Dry or moist	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	20	Boiling	48 h	0.051 (2) max	...	97
317L	S31703	...	...	85	Boiling	48 h	5 (196)	...	97
317L	S31703	...	...	85	Boiling	48 h	7 (294)	...	97
317L	S31703	...	...	30	Boiling	...	.16 (6.7)	...	219
317L	S31703	...	...	85	86 (150)	...	.005 (0.2)	...	219
317L	S31703	...	...	1	20 (68)	...	Resistant	...	253
317L	S31703	...	...	1	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	45	20 (68)	...	Resistant	...	253
317L	S31703	...	...	45	Boiling	...	Good	...	253
317L	S31703	...	...	60	20 (68)	...	Resistant	...	253
317L	S31703	...	...	60	Boiling	...	Good	...	253
317L	S31703	...	...	70	20 (68)	...	Resistant	...	253
317L	S31703	...	...	70	Boiling	...	Questionable	...	253
317L	S31703	...	...	80	20 (68)	...	Resistant	...	253
317L	S31703	...	...	80	Boiling	...	Questionable	...	253
317L	S31703	...	...	Concentrated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Concentrated	Boiling	...	Poor	...	253
317L	S31703	...	Dry or moist	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	1	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	1	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	45	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	45	Boiling	...	Good	...	253
317LN	S31725	...	...	60	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	60	Boiling	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	70	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	70	Boiling	...	Questionable	...	253
317LN	S31725	...	...	80	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	80	Boiling	...	Questionable	...	253
317LN	S31725	...	...	Concentrated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Concentrated	Boiling	...	Poor	...	253
317LN	S31725	...	Dry or moist	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	1	20 (68)	...	Resistant	...	253
321	S32100	...	...	1	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	45	20 (68)	...	Resistant	...	253
321	S32100	...	...	45	Boiling	...	Questionable	...	253
321	S32100	...	...	60	20 (68)	...	Resistant	...	253
321	S32100	...	...	60	Boiling	...	Questionable	...	253
321	S32100	...	...	70	20 (68)	...	Resistant	...	253
321	S32100	...	...	70	Boiling	...	Questionable	...	253
321	S32100	...	...	80	20 (68)	...	Good	...	253
321	S32100	...	...	80	Boiling	...	Poor	...	253
321	S32100	...	...	Concentrated	20 (68)	...	Good	...	253
321	S32100	...	...	Concentrated	Boiling	...	Poor	...	253
321	S32100	...	Dry or moist	...	20 (68)	...	Good	...	253
329	S32900	...	...	1	20 (68)	...	Resistant	...	253
329	S32900	...	...	1	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	45	20 (68)	...	Resistant	...	253
329	S32900	...	...	45	Boiling	...	Good	...	253
329	S32900	...	...	60	20 (68)	...	Resistant	...	253
329	S32900	...	...	60	Boiling	...	Good	...	253
329	S32900	...	...	70	20 (68)	...	Resistant	...	253
329	S32900	...	...	70	Boiling	...	Questionable	...	253
329	S32900	...	...	80	20 (68)	...	Resistant	...	253
329	S32900	...	...	80	Boiling	...	Questionable	...	253
329	S32900	...	...	Concentrated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Concentrated	Boiling	...	Poor	...	253
329	S32900	...	Dry or moist	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	1	20 (68)	...	Resistant	...	253
347	S34700	...	...	1	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	45	20 (68)	...	Resistant	...	253
347	S34700	...	...	45	Boiling	...	Questionable	...	253
347	S34700	...	...	60	20 (68)	...	Resistant	...	253
347	S34700	...	...	60	Boiling	...	Questionable	...	253
347	S34700	...	...	70	20 (68)	...	Resistant	...	253
347	S34700	...	...	70	Boiling	...	Questionable	...	253
347	S34700	...	...	80	20 (68)	...	Good	...	253
347	S34700	...	...	80	Boiling	...	Poor	...	253
347	S34700	...	...	Concentrated	20 (68)	...	Good	...	253
347	S34700	...	...	Concentrated	Boiling	...	Poor	...	253
347	S34700	...	Dry or moist	...	20 (68)	...	Good	...	253
403	S40300	...	...	1	Boiling	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	10	20 (68)	...	Questionable	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
403	S40300	...	...	45	20 (68)	...	Questionable	...	253
403	S40300	...	...	45	Boiling	...	Poor	...	253
403	S40300	...	...	60	20 (68)	...	Questionable	...	253
403	S40300	...	...	60	Boiling	...	Poor	...	253
403	S40300	...	...	70	20 (68)	...	Questionable	...	253
403	S40300	...	...	70	Boiling	...	Poor	...	253
403	S40300	...	...	80	20 (68)	...	Questionable	...	253
403	S40300	...	...	80	Boiling	...	Poor	...	253
403	S40300	...	...	Concentrated	20 (68)	...	Questionable	...	253
403	S40300	...	...	Concentrated	Boiling	...	Poor	...	253
405	S40500	...	...	1	Boiling	...	Good	...	253
405	S40500	...	...	10	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	45	20 (68)	...	Questionable	...	253
405	S40500	...	...	45	Boiling	...	Poor	...	253
405	S40500	...	...	60	20 (68)	...	Questionable	...	253
405	S40500	...	...	60	Boiling	...	Poor	...	253
405	S40500	...	...	70	20 (68)	...	Questionable	...	253
405	S40500	...	...	70	Boiling	...	Poor	...	253
405	S40500	...	...	80	20 (68)	...	Questionable	...	253
405	S40500	...	...	80	Boiling	...	Poor	...	253
405	S40500	...	...	Concentrated	20 (68)	...	Questionable	...	253
405	S40500	...	...	Concentrated	Boiling	...	Poor	...	253
409	S40900	...	...	1	Boiling	...	Good	...	253
409	S40900	...	...	10	20 (68)	...	Questionable	...	253
409	S40900	...	...	10	Boiling	...	Questionable	...	253
409	S40900	...	...	45	20 (68)	...	Questionable	...	253
409	S40900	...	...	45	Boiling	...	Poor	...	253
409	S40900	...	...	60	20 (68)	...	Questionable	...	253
409	S40900	...	...	60	Boiling	...	Poor	...	253
409	S40900	...	...	70	20 (68)	...	Questionable	...	253
409	S40900	...	...	70	Boiling	...	Poor	...	253
409	S40900	...	...	80	20 (68)	...	Questionable	...	253
409	S40900	...	...	80	Boiling	...	Poor	...	253
409	S40900	...	...	Concentrated	20 (68)	...	Questionable	...	253
409	S40900	...	...	Concentrated	Boiling	...	Poor	...	253
410	S41000	...	...	10	Room	...	Good	...	121
410	S41000	...	...	1	Boiling	...	Good	...	253
410	S41000	...	...	10	20 (68)	...	Questionable	...	253
410	S41000	...	...	10	Boiling	...	Questionable	...	253
410	S41000	...	...	45	20 (68)	...	Questionable	...	253
410	S41000	...	...	45	Boiling	...	Poor	...	253
410	S41000	...	...	60	20 (68)	...	Questionable	...	253
410	S41000	...	...	60	Boiling	...	Poor	...	253
410	S41000	...	...	70	20 (68)	...	Questionable	...	253
410	S41000	...	...	70	Boiling	...	Poor	...	253
410	S41000	...	...	80	20 (68)	...	Questionable	...	253
410	S41000	...	...	80	Boiling	...	Poor	...	253
410	S41000	...	...	Concentrated	20 (68)	...	Questionable	...	253
410	S41000	...	...	Concentrated	Boiling	...	Poor	...	253
410	S41000	...	Aerated	10	21 (70)	...	Good	...	121

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	Air free	10	21 (70)	...	Poor	...	121
416	S41600	...	...	1	Boiling	...	Good	...	253
416	S41600	...	...	10	20 (68)	...	Questionable	...	253
416	S41600	...	...	10	Boiling	...	Questionable	...	253
416	S41600	...	...	45	20 (68)	...	Questionable	...	253
416	S41600	...	...	45	Boiling	...	Poor	...	253
416	S41600	...	...	60	20 (68)	...	Questionable	...	253
416	S41600	...	...	60	Boiling	...	Poor	...	253
416	S41600	...	...	70	20 (68)	...	Questionable	...	253
416	S41600	...	...	70	Boiling	...	Poor	...	253
416	S41600	...	...	80	20 (68)	...	Questionable	...	253
416	S41600	...	...	80	Boiling	...	Poor	...	253
416	S41600	...	...	Concentrated	20 (68)	...	Questionable	...	253
416	S41600	...	...	Concentrated	Boiling	...	Poor	...	253
420	S42000	...	...	1	Boiling	...	Good	...	253
420	S42000	...	...	10	20 (68)	...	Questionable	...	253
420	S42000	...	...	10	Boiling	...	Questionable	...	253
420	S42000	...	...	45	20 (68)	...	Questionable	...	253
420	S42000	...	...	45	Boiling	...	Poor	...	253
420	S42000	...	...	60	20 (68)	...	Questionable	...	253
420	S42000	...	...	60	Boiling	...	Poor	...	253
420	S42000	...	...	70	20 (68)	...	Questionable	...	253
420	S42000	...	...	70	Boiling	...	Poor	...	253
420	S42000	...	...	80	20 (68)	...	Questionable	...	253
420	S42000	...	...	80	Boiling	...	Poor	...	253
420	S42000	...	...	Concentrated	20 (68)	...	Questionable	...	253
420	S42000	...	...	Concentrated	Boiling	...	Poor	...	253
430	S43000	...	...	1	20 (68)	...	Resistant	...	253
430	S43000	...	...	1	Boiling	...	Good	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	45	20 (68)	...	Questionable	...	253
430	S43000	...	...	45	Boiling	...	Questionable	...	253
430	S43000	...	...	60	20 (68)	...	Questionable	...	253
430	S43000	...	...	60	Boiling	...	Poor	...	253
430	S43000	...	...	70	20 (68)	...	Questionable	...	253
430	S43000	...	...	70	Boiling	...	Poor	...	253
430	S43000	...	...	80	20 (68)	...	Questionable	...	253
430	S43000	...	...	80	Boiling	...	Poor	...	253
430	S43000	...	...	Concentrated	20 (68)	...	Questionable	...	253
430	S43000	...	...	Concentrated	Boiling	...	Poor	...	253
430	S43000	...	Aerated	10	21 (70)	...	Good	...	121
430	S43000	...	Air free	10	21 (70)	...	Poor	...	121
434	S43400	...	...	1	20 (68)	...	Resistant	...	253
434	S43400	...	...	1	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	45	20 (68)	...	Good	...	253
434	S43400	...	...	45	Boiling	...	Questionable	...	253
434	S43400	...	...	60	20 (68)	...	Good	...	253
434	S43400	...	...	60	Boiling	...	Questionable	...	253
434	S43400	...	...	70	20 (68)	...	Good	...	253
434	S43400	...	...	70	Boiling	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	80	20 (68)	...	Good	...	253
434	S43400	...	...	80	Boiling	...	Poor	...	253
434	S43400	...	...	Concentrated	20 (68)	...	Good	...	253
434	S43400	...	...	Concentrated	Boiling	...	Poor	...	253
434	S43400	...	Dry or moist	...	20 (68)	...	Good	...	253
444	S44400	...	No activation	50	Boiling	24 h	0.11 (4.4)	...	52
AL 2205	S31803	...	...	...	...	...	.04 (1.6)	...	219
AL 2205	S31803	...	...	...	...	...	.010 (0.4)	...	219
Alloy 20	...	Welded	...	53	65 (150)	28 d	0.01 (0.4)	...	212
Alloy 20	...	Welded	...	53	93 (200)	28 d	0.10 (4)	...	212
Alloy 20	...	Welded	...	53	132 (270)	28 d	1.0 (40)	...	212
Alloy 904L	N08904	...	Plus 3 ppm chloride and 59 ppm arsenic	75	200 (390)	6 h	37 (1470)	...	242
AM-363	S36300	...	...	...	Room	...	Poor	...	120
Carpenter 20Cb3	N08020	...	...	10	101 (214)	96 h	0.025 (1) max	...	156
Carpenter 20Cb3	N08020	...	...	50	110 (230)	96 h	0.43 (17)	...	156
Carpenter 20Cb3	N08020	...	...	60	Boiling	20 h	0.23 (9)	...	156
Carpenter 20Cb3	N08020	...	...	70	Boiling	20 h	0.28 (11)	...	156
Carpenter 20Cb3	N08020	...	...	85	Boiling	20 h	1.0 (38)	...	156
Carpenter 20Cb3	N08020	...	...	86	97 (208)	96 h	0.05 (2)	...	156
Carpenter 20Cb3	N08020	...	CP grade. Three 24-h periods	85	160 (320)	24 h	1.4 (54)	...	156,164
Carpenter 20Mo-6	N08026	...	Lab tests. Reagent grade concentrated	85	Boiling	144 h	0.7 (26)	...	145
Carpenter 20Mo-6	N08026	...	Lab tests. Wet process acid (68.9% phosphoric acid, 4.15% sulfuric acid, 1.85% iron, 5400 ppm fluorides, 2000 ppm chlorides). Samples activated immediately prior to test	68.9	100 (212)	144 h	0.08 (3)	...	145
Carpenter 20Mo-6	N08026	...	Wet process supersphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. First stage	70	160 (320)	87 d	0.16 (6.3)	...	145
Carpenter 20Mo-6	N08026	...	Wet process supersphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. Second stage. Residue formed on surface during exposure. The residue contained 81,000 ppm chlorides, 1500 ppm fluorides	70	188 (370)	87 d	0.55 (22)	...	145
Durimet 20	J95150	...	...	78-85	115 (240)	...	0.23 (9.2)	...	156
Durimet 20	J95150	...	P_2O_5 equivalent 75-77%	104-106	104 (220)	...	0.002 (0.1)	...	156
F51	S31803	...	...	1	20 (68)	...	Resistant	...	253
F51	S31803	...	...	1	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	45	20 (68)	...	Resistant	...	253
F51	S31803	...	...	45	Boiling	...	Good	...	253
F51	S31803	...	...	60	20 (68)	...	Resistant	...	253
F51	S31803	...	...	60	Boiling	...	Good	...	253
F51	S31803	...	...	70	20 (68)	...	Resistant	...	253
F51	S31803	...	...	70	Boiling	...	Questionable	...	253
F51	S31803	...	...	80	20 (68)	...	Resistant	...	253
F51	S31803	...	...	80	Boiling	...	Questionable	...	253
F51	S31803	...	...	Concentrated	20 (68)	...	Resistant	...	253

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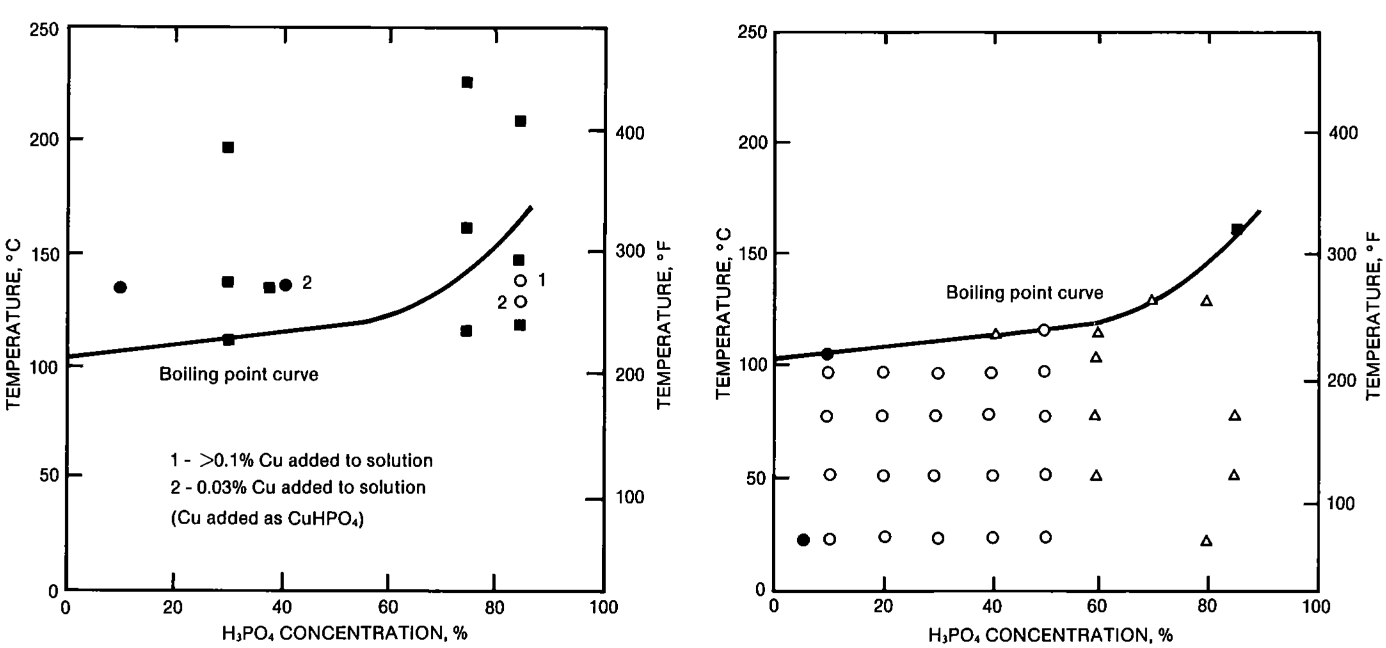
Corrosion Behavior of Various Metals and Alloys in Phosphoric Acid (Continued)

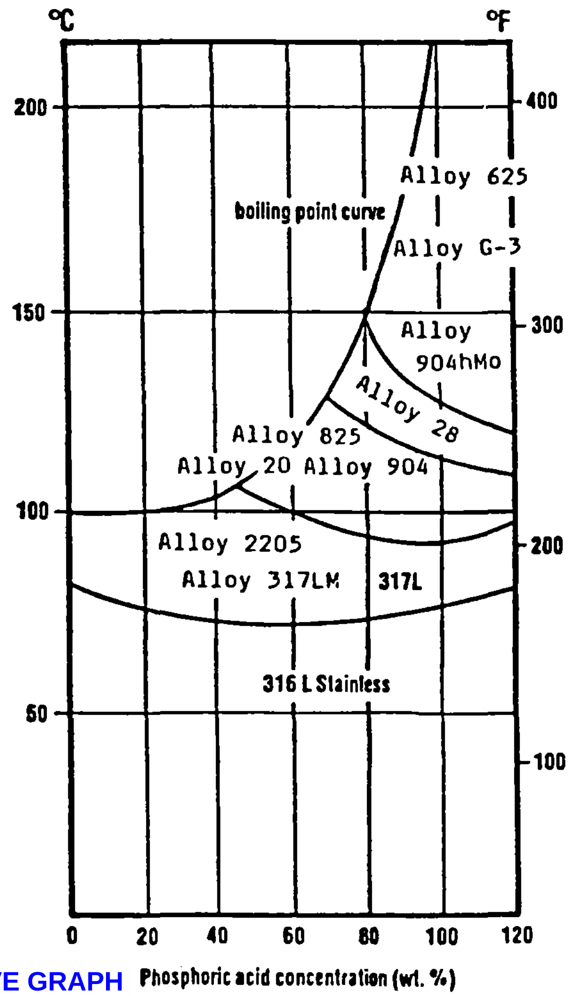
Material	UNS	Condition	Comments	Concen- tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
F51	S31803	...	...	Concentrated	Boiling	...	Poor	...	253
F51	S31803	...	Dry or moist	...	20 (68)	...	Resistant	...	253
Ferralium 255	S32550	...	...	...	...	...	.005 (0.2)	...	219
Ferralium 255	S32550	...	...	...	...	...	.003 (0.1)	...	219
Jessop JS700	N08700	...	...	20	Boiling	48 h	0.05 (2) max	...	97
Jessop JS700	N08700	...	...	54	121 (250)	48 h	0.06 (2.4)	...	97
Jessop JS700	N08700	...	...	60	Boiling	48 h	1.5 (59)	...	97
Jessop JS700	N08700	...	...	85	Boiling	48 h	3.1 (122)	...	97
Jessop JS700	N08700	...	Plus 2% HF	25	75 (167)	48 h	0.20 (8)	...	97
JS777	N08777	...	Maximum corrosion rate	54	116 (241)	96 h	13.0 (518)	...	212
JS777	N08777	...	Maximum corrosion rate	54	149 (300)	96 h	30 (1191)	...	212
JS777	N08777	...	Maximum corrosion rate	70	204 (400)	96 h	0.58 (23)	...	212
Uddeholm alloy 904L	N08904	...	...	70	160 (320)	87 d	0.003 (0.11)	...	145
Uddeholm alloy 904L	N08904	...	Lab tests. Wet process acid (68.9% phosphoric acid, 4.15% sulfuric acid, 1.85% iron, 5400 ppm fluorides, 2000 ppm chlorides). Samples activated immediately prior to test	68.9	100 (212)	144 h	0.18 (7)	...	145
Uddeholm alloy 904L	N08904	...	Wet process superphosphoric acid evaporator. Plus 3% sulfates, 6000 ppm fluorides. First stage	70	188 (370)	87 d	0.008 (0.3)	...	145
Worthite	J95150	...	CP grade. Three 24-h periods	85	160 (320)	24 h	3.27 (129)	...	156,164



a) LIVE GRAPH Click here to view

b) LIVE GRAPH Click here to view

ACI CF-8. Isocorrosion diagrams for ACI CF-8 in phosphoric acid. (a) Test performed in a closed container at equilibrium pressure. (b) Tested at atmospheric pressure. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 579.



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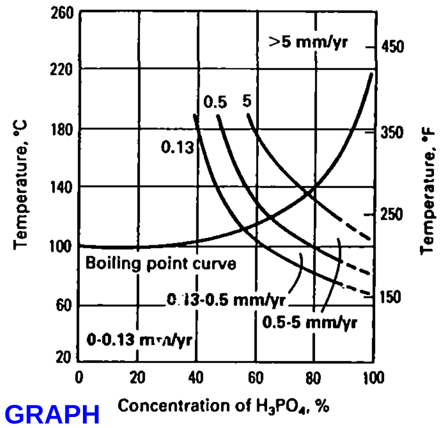
Various alloys. Areas of applicability for various alloys in phosphoric acid. Source: C.M. Schillmoller, "Corrosion in Phosphoric Acid Plants," in *Process Industries Corrosion*, B.J. Moniz and W.I. Pollock, Ed., National Association of Corrosion Engineers, Houston, 1986, 165.



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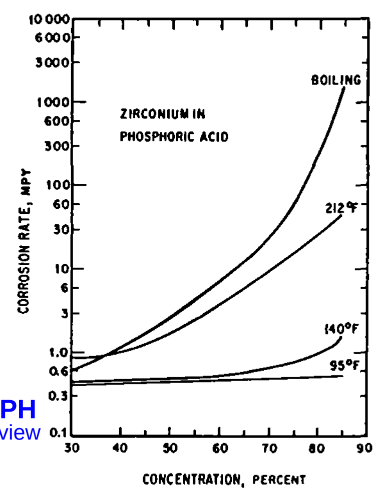
Zirconium. Isocorrosion diagram for zirconium in phosphoric acid. Source: "Zircadyne Corrosion Properties," Teledyne Wah Chang Albany, 1986.



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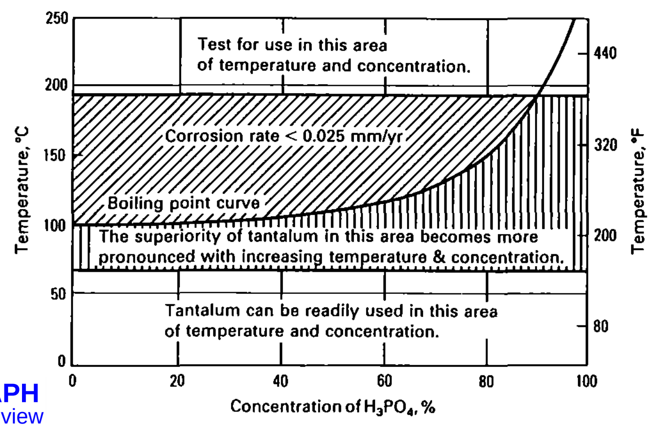
Zirconium. Corrosion rate of zirconium in phosphoric acid. Source: *ASTM Manual on Zirconium and Hafnium* (STP 639), J.H. Schemel, Ed., ASTM, Philadelphia, 1977, 37.



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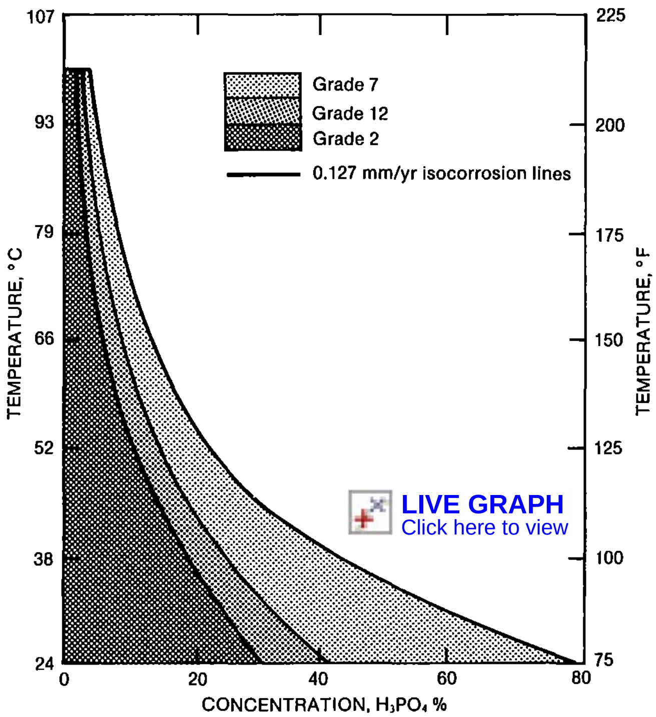
Tantalum. Corrosion resistance of tantalum in phosphoric acid of various concentrations and temperatures. Source: M. Stern and C.R. Bishop, Corrosion and Electrochemical Behavior, in *Columbium and Tantalum*, F.T. Sisco and E. Epremian, Ed., John Wiley & Sons, New York, 1963.



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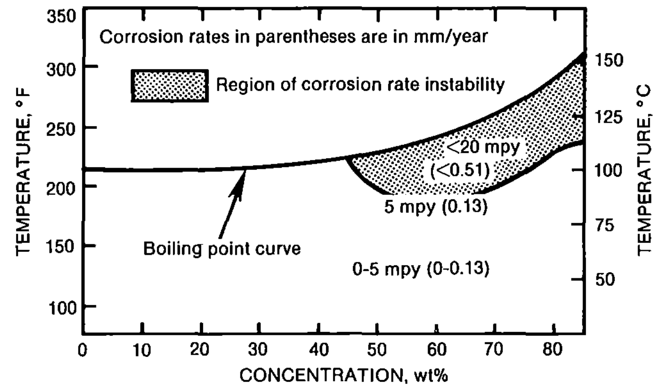
Titanium alloys. Isocorrosion diagram for titanium alloys in pure, naturally aerated phosphoric acid solutions. The 0.127-mm/yr (5-mils/yr) isocorrosion lines are indicated. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH 1987, 680.



Nickel-base alloy. Resistance of Hastelloy B-2 to phosphoric acid. All test specimens were solution heat treated at 1066 °C (1950 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.

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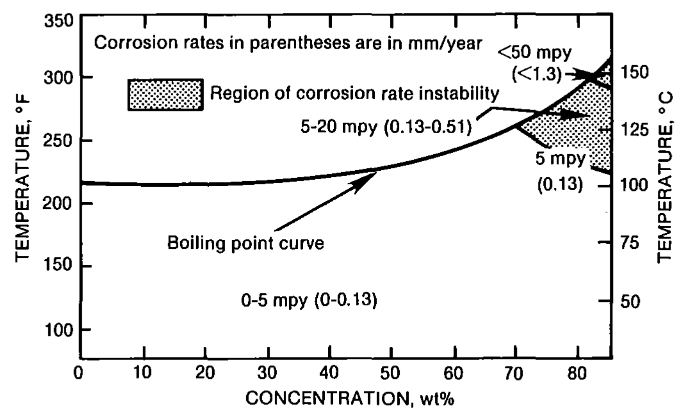

Nickel-base alloy. Resistance of Hastelloy C-4 to phosphoric acid. All test specimens were solution heat treated at 1066 °C (1950 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1983.

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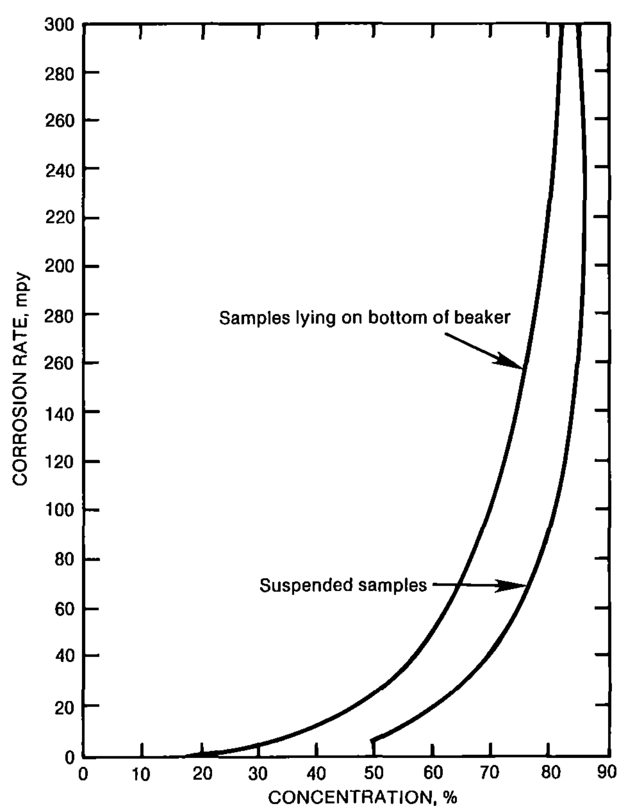

Nickel-base alloy. Corrosion of Inconel 625 in boiling phosphoric acid solutions. Source: Inco Alloys International, 1985.

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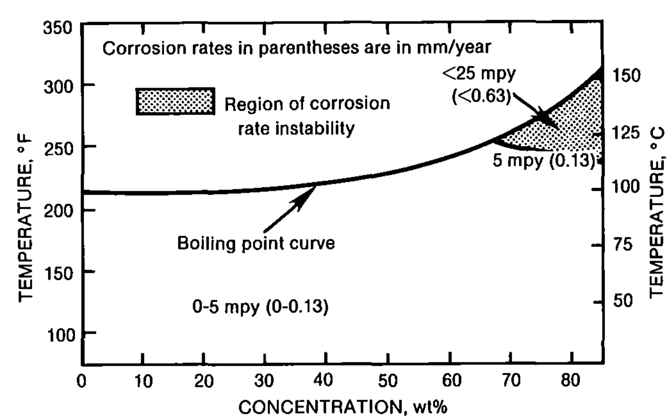

Nickel-base alloy. Resistance of Hastelloy C-276 to phosphoric acid. All test specimens were heat treated at 1121 °C (2050 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.

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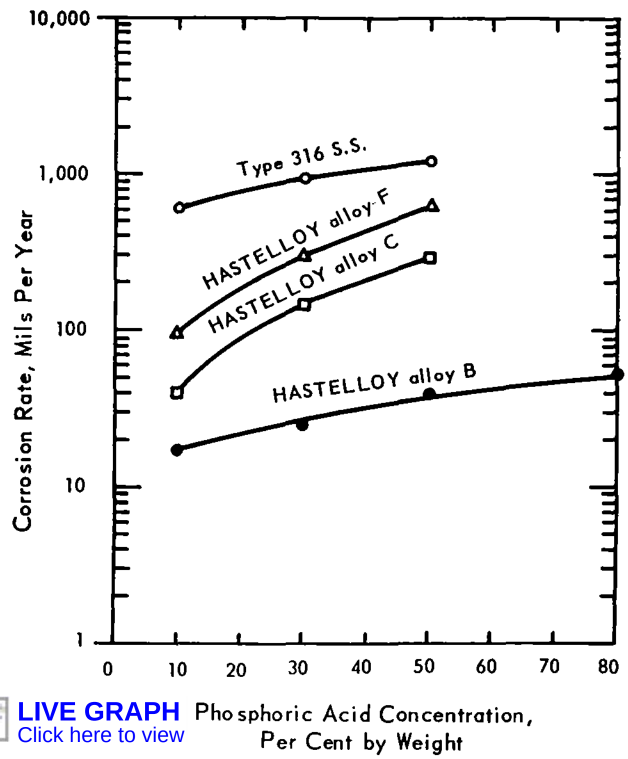

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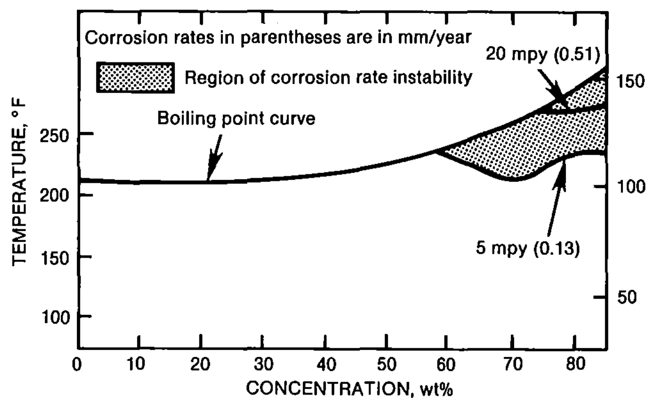
Nickel-base alloys. Corrosion tests on nickel-base alloys and type 316 stainless steel in phosphoric acid at 190 °C (374 °F). Curves are included not only for Hastelloy B, but for Hastelloy C and F and type 316 stainless steel. Shown are the corrosion rates in pure phosphoric acid solutions at 190 °C (374 °F) for one 65-h period using sealed tubes above the boiling point. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



Nickel-base alloy. Resistance of Hastelloy G-30 to phosphoric acid. All test specimens were heat treated at 1177 °C (2150 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.

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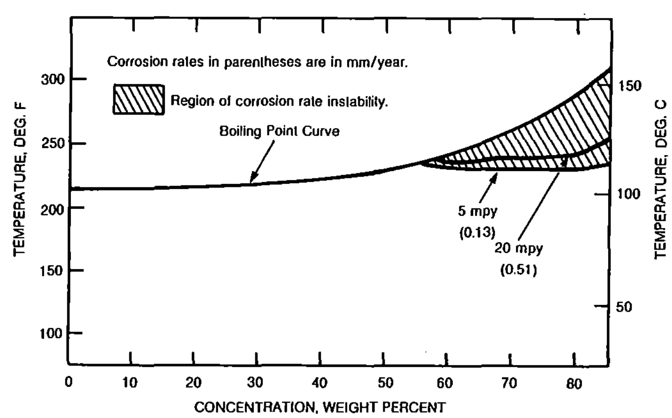

Nickel-base alloys. Corrosion resistance of Hastelloy C-22 to phosphoric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.

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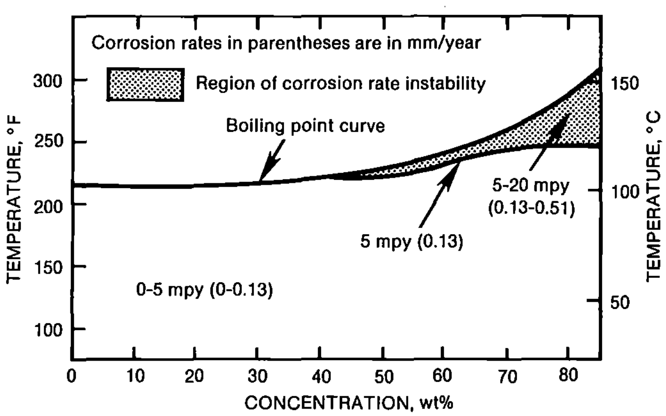

Nickel-base alloy. Resistance of Hastelloy G-3 to phosphoric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1987.

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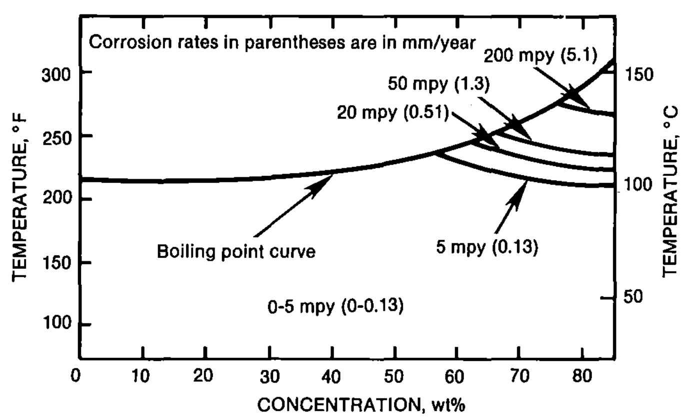

Duplex stainless steel. Resistance of Ferralium 255 to phosphoric acid. All test specimens were solution heat treated and in the unwelded condition.

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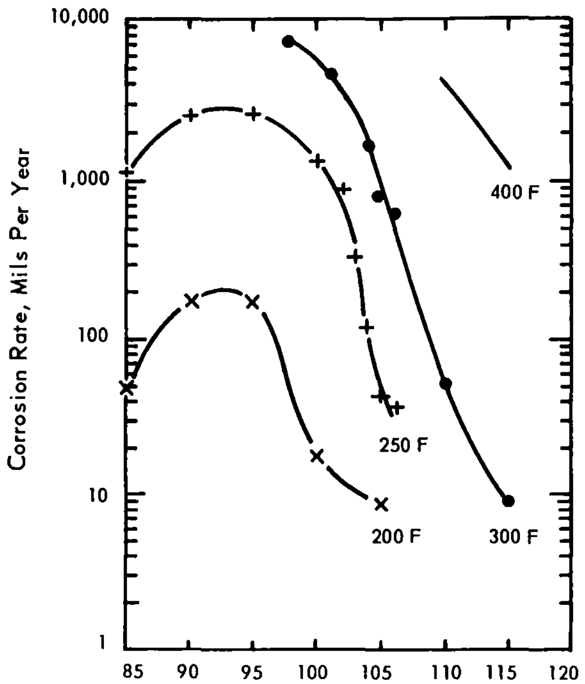

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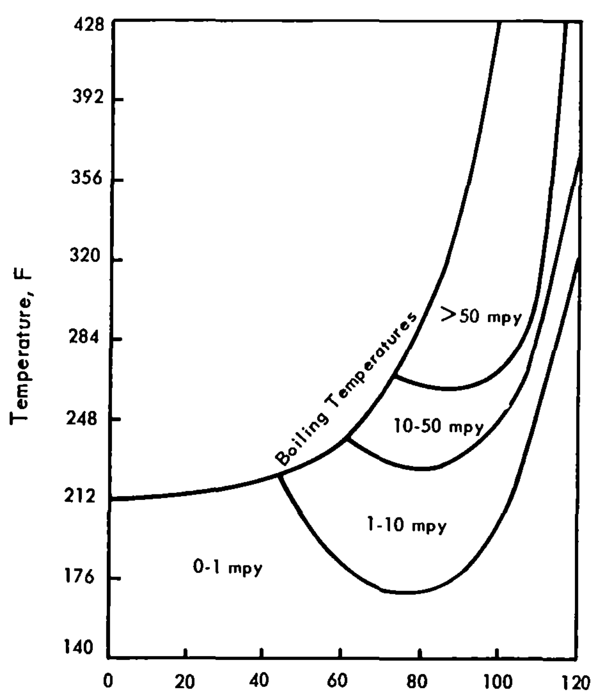
Stainless steel. Corrosion of type 317 stainless steel in phosphoric acid. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



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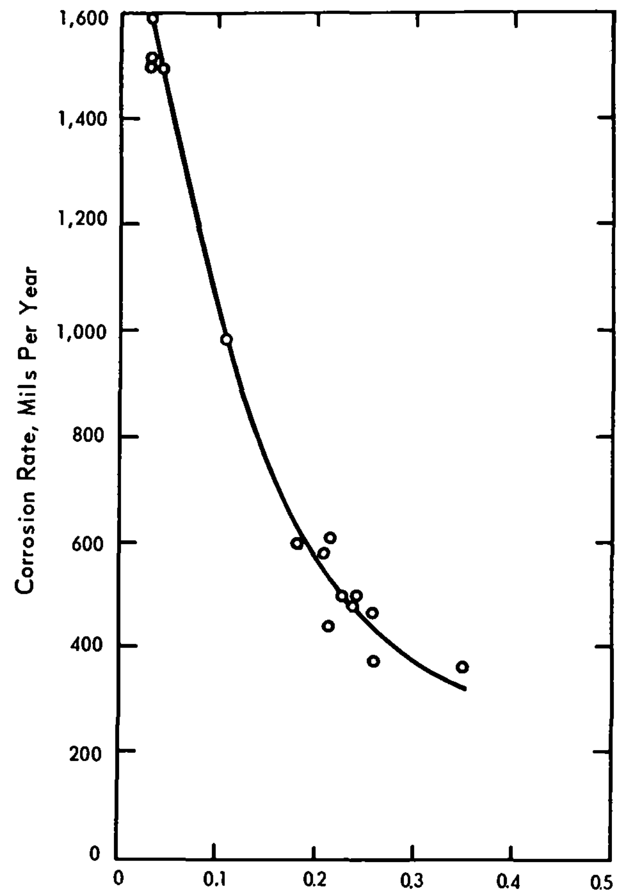
Stainless steel. Isocorrosion chart for type 316 stainless steel in furnace-grade phosphoric acid under mildly agitated conditions. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



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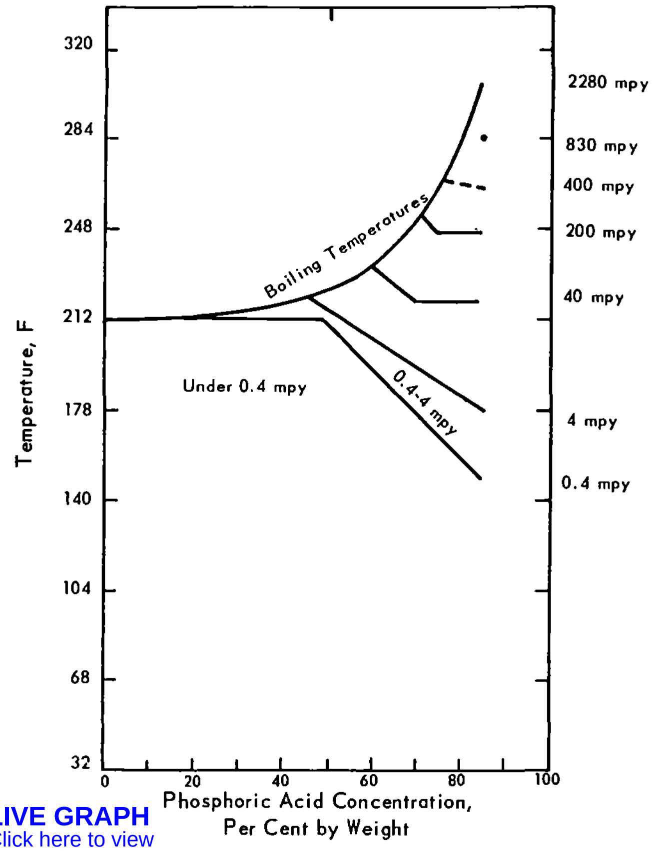
Stainless steel. Effect of copper content in type 316L stainless steel on resistance to corrosion in boiling 85% phosphoric acid. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



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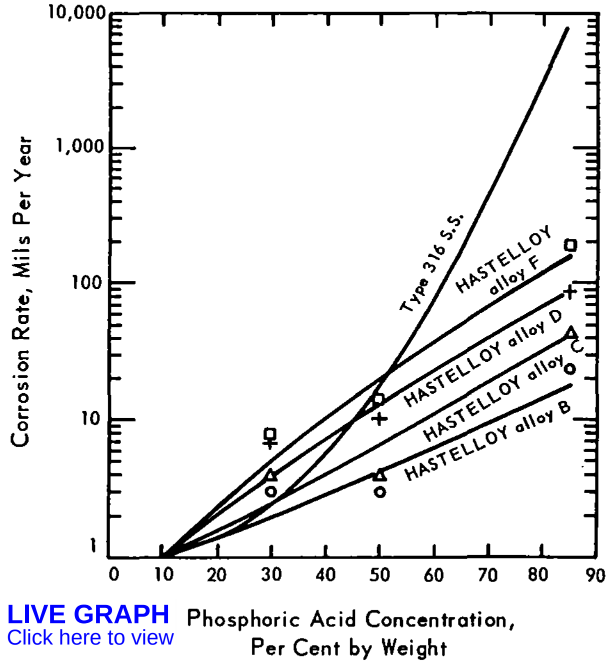
Stainless steel. Corrosion of wrought 18-9 stainless steel in phosphoric acid. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



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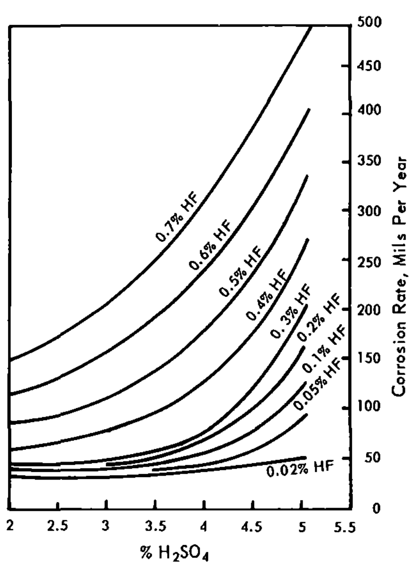
Stainless steel. Corrosion tests on nickel-base alloys and type 316 stainless steel in boiling phosphoric acid. Curves are included not only for Hastelloy B, but for Hastelloy C, D and F, and type 316 stainless steel. Shown are the corrosion rates in pure phosphoric acid solutions at the boiling point for three 48-h periods (five 24-h periods for Hastelloy D). Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.



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Stainless steel. Corrosion rate of type 316 stainless steel in 35% phosphoric acid at 88 °C (190 °F). Further evidence is found in a series of pilot plant tests in hot phosphoric acid containing hydrofluosilic acid and controlled contents of hydrofluoric and sulfuric acids, simulating wet-process acid. These three additions increase the corrosivity of the hot solution. Source: "Corrosion Resistance of Nickel-Containing Alloys in Phosphoric Acid," The International Nickel Company, 1976.

Phosphorus

Phosphorus, P, occurs in three distinct allotropes. The white phosphorus is a yellowish-white solid that is very poisonous, phosphorescent in the dark, and self-ignites in air. It has a melting point of 44 °C (111 °F) and is insoluble in water and alcohol. White phosphorus is used in manufacturing smoke screens, rat poisons, and matches. Red phosphorus is insoluble in all solvents, sublimes at 416 °C (780 °F), and is nonpoisonous. The black allotrope has lustrous crystals and is insoluble in most solvents. Phosphorus is essential to plant and animal nutrition, but does not occur naturally in the elemental form because of its reactivity. Most phosphorus ores are converted into phosphoric acid.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 1100 has shown to be resistant to solid and liquid white phosphorus during limited tests at ambient temperature. Molten phosphorus has been serviced by water-cooled aluminum alloy pans.

Osmium. Osmium burns in the vapor of phosphorus.

Tantalum. Tantalum filings heated in phosphorus vapor at 750 to 950 °C (1380 to 1740 °F) form tantalum phosphides.

Corrosion Behavior of Various Metals and Alloys in Phosphorous

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	...	...	...	...	Questionable	...	92
Nickel and alloys									
Alloy 800H	N08810	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	.28 (11)	...	63
Alloy 825	N08825	...	Chemical (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus water, hydrogen, phosphine, hydrocarbon, traces of carbon dioxide and carbon monoxide, pH 3-6 (vapors, liquid)	...	80 (176)	112 d	.06 (2.4)	...	89
Hastelloy alloy S	N06635	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	.23 (9)	...	63
Hastelloy alloy X	N06002	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	0.08 (3)	...	63
Haynes alloy No.214	...	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	0.20 (8)	...	63
Refractory metals and alloys									
Haynes alloy No.556	R30556	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	0.15 (6)	...	63
Haynes alloy No.188	R30188	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	0.23 (9)	...	63

(Continued)

Corrosion Behavior of Various Metals and Alloys in Phosphorous (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
304	S30400	...	Based on field tests in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds	...	800 (1475)	30 d	.38 (15)	...	63
304	S30400	...	Chemical (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus water, hydrogen, phosphine, hydrocarbon, traces of carbon dioxide and carbon monoxide, pH 3-6 (vapors, liquid)	...	80 (176)	112 d	.08 (3.1)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; silght to moderate aeration; no agitation	...	60 (140)	185 d	0.003 (0.1) max	...	89
304	S30400	...	Research lab test; no aeration; no agitation. With carbon over the standard maximum	...	65-70 (149-158)	...	0.003 (0.1)	...	89
316	S31600	...	Chemical (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus water, hydrogen, phosphine, hydrocarbon, traces of carbon dioxide and carbon monoxide, pH 3-6 (vapors, liquid)	...	80 (176)	112 d	.07 (2.9)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; silght to moderate aeration; no agitation	...	60 (140)	185 d	0.003 (0.1) max	...	89
316	S31600	...	Research lab test; no aeration; no agitation	...	65-70 (149-158)	...	0.003 (0.1) max	...	89
317	S31700	...	Chemical (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus water, hydrogen, phosphine, hydrocarbon, traces of carbon dioxide and carbon monoxide, pH 3-6 (vapors, liquid)	...	80 (176)	112 d	.06 (2.5)	...	89
Carpenter 20	...	...	Chemical (distillation) processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus water, hydrogen, phosphine, hydrocarbon, traces of carbon dioxide and carbon monoxide, pH 3-6 (vapors, liquid)	...	80 (176)	112 d	.07 (2.8)	...	89

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Picric Acid

Also known as picronitric acid, trinitrophenol, nitroxanthic acid, carbazotic acid or phenoltrinitrate, $C_6H_2(NO_2)_3OH$ is yellow crystals that are soluble in water, alcohol, chloroform, benzene, and ether with a very bitter taste. It is derived by the nitration of phenolsulfonic acid, obtained by heating phenol with concentrated sulfuric acid, and is used for explosives, matches, electric batteries, and etching copper.

Corrosion Behavior of Various Metals and Alloys in Picric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253

Potassium Acetate

Potassium acetate, $KC_2H_3O_2$, is a white, deliquescent solid, soluble in water and alcohol, insoluble in ether, that melts at 292 °C. It is used as an analytical reagent, dehydrating agent, in medicine, and in crystal glass manufacture.

Corrosion Behavior of Various Metals and Alloys in Potassium Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Molten	...	Resistant	...	253
302	S30200	...	...	...	Molten	...	Resistant	...	253

(Continued)

Previous Page

Corrosion Behavior of Various Metals and Alloys in Potassium Acetate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	...	Molten	...	Resistant	...	253
304	S30400	...	...	...	Molten	...	Resistant	...	253
304L	S30403	...	...	...	Molten	...	Resistant	...	253
304LN	S30453	...	...	...	Molten	...	Resistant	...	253
316	S31600	...	...	...	Molten	...	Resistant	...	253
316F	S31620	...	...	...	Molten	...	Resistant	...	253
316L	S31603	...	...	...	Molten	...	Resistant	...	253
316LN	S31653	...	...	...	Molten	...	Resistant	...	253
316Ti	S31635	...	...	...	Molten	...	Resistant	...	253
317L	S31703	...	...	...	Molten	...	Resistant	...	253
317LN	S31725	...	...	...	Molten	...	Resistant	...	253
321	S32100	...	...	...	Molten	...	Resistant	...	253
329	S32900	...	...	...	Molten	...	Resistant	...	253
347	S34700	...	...	...	Molten	...	Resistant	...	253
F51	S31803	...	...	...	Molten	...	Resistant	...	253

Potassium Aluminum Sulfate

Also known as potash alum, alum NF, and potassium alum, $Al_2(SO_4)_3{\cdot}K_2SO_4{\cdot}24H_2O$ (sometimes written $AlK(SO_4)_2{\cdot}12H_2O$) is white, odorless crystals having an astringent taste, and is soluble in water, insoluble in alcohol, and noncombustible. Solutions in water are acid. Derived from alumite, leucite, or similar minerals, and also by crystallization from a solution made by dissolving aluminum sulfate and potassium sulfate and mixing. Used in dyeing (mordant), paper, matches, paints, tanning agents, waterproofing agents, purification of water, aluminum salts, food additive, baking powder, astringent, and as a cement hardener.

Corrosion Behavior of Various Metals and Alloys in Potassium Aluminum Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Good	...	253
301	S30100	...	...	Hot saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Hot saturated	Boiling	...	Poor	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Good	...	253
302	S30200	...	...	Hot saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Hot saturated	Boiling	...	Poor	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	Hot saturated	20 (68)	...	Questionable	...	253
303	S30300	...	...	Hot saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Hot saturated	Boiling	...	Poor	...	253
303	S30300	...	...	Hot saturated	Boiling	...	Poor	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	10	Boiling	...	Good	...	253
304	S30400	...	...	Hot saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Hot saturated	Boiling	...	Poor	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Good	...	253
304L	S30403	...	...	Hot saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Hot saturated	Boiling	...	Poor	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Good	...	253
304LN	S30453	...	...	Hot saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Hot saturated	Boiling	...	Poor	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	Hot saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Hot saturated	Boiling	...	Questionable	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Good	...	253
316F	S31620	...	...	Hot saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Hot saturated	Boiling	...	Poor	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	Hot saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Hot saturated	Boiling	...	Questionable	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Hot saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Hot saturated	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Hot saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Hot saturated	Boiling	...	Questionable	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	Hot saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Hot saturated	Boiling	...	Questionable	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Hot saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Hot saturated	Boiling	...	Questionable	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Good	...	253
321	S32100	...	...	Hot saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Hot saturated	Boiling	...	Poor	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	Hot saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Hot saturated	Boiling	...	Questionable	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Good	...	253
347	S34700	...	...	Hot saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Hot saturated	Boiling	...	Poor	...	253
403	S40300	...	...	10	20 (68)	...	Good	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
403	S40300	...	...	Hot saturated	20 (68)	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Aluminum Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	Hot saturated	Boiling	...	Poor	...	253
405	S40500	...	...	10	20 (68)	...	Good	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	Hot saturated	20 (68)	...	Questionable	...	253
405	S40500	...	...	Hot saturated	Boiling	...	Poor	...	253
409	S40900	...	...	10	20 (68)	...	Good	...	253
409	S40900	...	...	10	Boiling	...	Questionable	...	253
409	S40900	...	...	Hot saturated	20 (68)	...	Questionable	...	253
409	S40900	...	...	Hot saturated	Boiling	...	Poor	...	253
410	S41000	...	...	10	20 (68)	...	Good	...	253
410	S41000	...	...	10	Boiling	...	Questionable	...	253
410	S41000	...	...	Hot saturated	20 (68)	...	Questionable	...	253
410	S41000	...	...	Hot saturated	Boiling	...	Poor	...	253
416	S41600	...	...	10	20 (68)	...	Good	...	253
416	S41600	...	...	10	Boiling	...	Questionable	...	253
416	S41600	...	...	Hot saturated	20 (68)	...	Questionable	...	253
416	S41600	...	...	Hot saturated	Boiling	...	Poor	...	253
420	S42000	...	...	10	20 (68)	...	Good	...	253
420	S42000	...	...	10	Boiling	...	Questionable	...	253
420	S42000	...	...	Hot saturated	20 (68)	...	Questionable	...	253
420	S42000	...	...	Hot saturated	Boiling	...	Poor	...	253
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	Hot saturated	20 (68)	...	Questionable	...	253
430	S43000	...	...	Hot saturated	Boiling	...	Poor	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Good	...	253
434	S43400	...	...	Hot saturated	20 (68)	...	Good	...	253
434	S43400	...	...	Hot saturated	Boiling	...	Poor	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	Hot saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Hot saturated	Boiling	...	Questionable	...	253

Potassium Bisulfate

Also known as acid potassium sulfate and potassium acid sulfate, $KHSO_4$ is water soluble, colorless crystals, which melt at 214 °C. It is used in winemaking, fertilizer manufacture, and as a flux and food preservative.

Corrosion Behavior of Various Metals and Alloys in Potassium Bisulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	2	90 (194)	...	Poor	...	253
301	S30100	...	...	5	20 (68)	...	Good	...	253
301	S30100	...	...	5	90 (194)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Bisulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	15	90 (194)	...	Poor	...	253
302	S30200	...	...	2	90 (194)	...	Poor	...	253
302	S30200	...	...	5	20 (68)	...	Good	...	253
302	S30200	...	...	5	90 (194)	...	Poor	...	253
302	S30200	...	...	15	90 (194)	...	Poor	...	253
303	S30300	...	...	2	90 (194)	...	Poor	...	253
303	S30300	...	...	5	20 (68)	...	Good	...	253
303	S30300	...	...	5	90 (194)	...	Poor	...	253
303	S30300	...	...	15	90 (194)	...	Poor	...	253
304	S30400	...	...	2	90 (194)	...	Poor	...	253
304	S30400	...	...	5	20 (68)	...	Good	...	253
304	S30400	...	...	5	90 (194)	...	Poor	...	253
304	S30400	...	...	15	90 (194)	...	Poor	...	253
304L	S30403	...	...	2	90 (194)	...	Poor	...	253
304L	S30403	...	...	5	20 (68)	...	Good	...	253
304L	S30403	...	...	5	90 (194)	...	Poor	...	253
304L	S30403	...	...	15	90 (194)	...	Poor	...	253
304LN	S30453	...	...	2	90 (194)	...	Poor	...	253
304LN	S30453	...	...	5	20 (68)	...	Good	...	253
304LN	S30453	...	...	5	90 (194)	...	Poor	...	253
304LN	S30453	...	...	15	90 (194)	...	Poor	...	253
316	S31600	...	...	2	90 (194)	...	Questionable	...	253
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316	S31600	...	...	5	90 (194)	...	Questionable	...	253
316	S31600	...	...	15	90 (194)	...	Questionable	...	253
316F	S31620	...	...	2	90 (194)	...	Poor	...	253
316F	S31620	...	...	5	20 (68)	...	Good	...	253
316F	S31620	...	...	5	90 (194)	...	Poor	...	253
316F	S31620	...	...	15	90 (194)	...	Poor	...	253
316L	S31603	...	...	2	90 (194)	...	Questionable	...	253
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	90 (194)	...	Questionable	...	253
316L	S31603	...	...	15	90 (194)	...	Questionable	...	253
316LN	S31653	...	...	2	90 (194)	...	Questionable	...	253
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	90 (194)	...	Questionable	...	253
316LN	S31653	...	...	15	90 (194)	...	Questionable	...	253
316Ti	S31635	...	...	2	90 (194)	...	Questionable	...	253
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	90 (194)	...	Questionable	...	253
316Ti	S31635	...	...	15	90 (194)	...	Questionable	...	253
317L	S31703	...	...	2	90 (194)	...	Questionable	...	253
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	5	90 (194)	...	Questionable	...	253
317L	S31703	...	...	15	90 (194)	...	Questionable	...	253
317LN	S31725	...	...	2	90 (194)	...	Questionable	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	90 (194)	...	Questionable	...	253
317LN	S31725	...	...	15	90 (194)	...	Questionable	...	253
321	S32100	...	...	2	90 (194)	...	Poor	...	253
321	S32100	...	...	5	20 (68)	...	Good	...	253
321	S32100	...	...	5	90 (194)	...	Poor	...	253
321	S32100	...	...	15	90 (194)	...	Poor	...	253
329	S32900	...	...	2	90 (194)	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Bisulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
329	S32900	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	90 (194)	...	Questionable	...	253
329	S32900	...	...	15	90 (194)	...	Questionable	...	253
347	S34700	...	...	2	90 (194)	...	Poor	...	253
347	S34700	...	...	5	20 (68)	...	Good	...	253
347	S34700	...	...	5	90 (194)	...	Poor	...	253
347	S34700	...	...	15	90 (194)	...	Poor	...	253
434	S43400	...	...	5	20 (68)	...	Good	...	253
F51	S31803	...	...	2	90 (194)	...	Questionable	...	253
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	5	90 (194)	...	Questionable	...	253
F51	S31803	...	...	15	90 (194)	...	Questionable	...	253

Potassium Bitartrate

Also known as cream of tartar and potassium acid tartrate, $KHC_4H_4O_6$ is white water soluble crystals or powder that is used in baking powder, for medicine, and as an acid and buffer in foods.

Corrosion Behavior of Various Metals and Alloys in Potassium Bitartrate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Hot saturated	Cold	...	Resistant	...	253
301	S30100	...	...	Hot saturated	Boiling	...	Questionable	...	253
302	S30200	...	...	Hot saturated	Cold	...	Resistant	...	253
302	S30200	...	...	Hot saturated	Boiling	...	Questionable	...	253
303	S30300	...	...	Hot saturated	Cold	...	Resistant	...	253
303	S30300	...	...	Hot saturated	Boiling	...	Questionable	...	253
304	S30400	...	...	Hot saturated	Cold	...	Resistant	...	253
304	S30400	...	...	Hot saturated	Boiling	...	Questionable	...	253
304L	S30403	...	...	Hot saturated	Cold	...	Resistant	...	253
304L	S30403	...	...	Hot saturated	Boiling	...	Questionable	...	253
304LN	S30453	...	...	Hot saturated	Cold	...	Resistant	...	253
304LN	S30453	...	...	Hot saturated	Boiling	...	Questionable	...	253
316	S31600	...	...	Hot saturated	Cold	...	Resistant	...	253
316	S31600	...	...	Hot saturated	Boiling	...	Good	...	253
316F	S31620	...	...	Hot saturated	Cold	...	Resistant	...	253
316F	S31620	...	...	Hot saturated	Boiling	...	Questionable	...	253
316L	S31603	...	...	Hot saturated	Cold	...	Resistant	...	253
316L	S31603	...	...	Hot saturated	Boiling	...	Good	...	253
316LN	S31653	...	...	Hot saturated	Cold	...	Resistant	...	253
316LN	S31653	...	...	Hot saturated	Boiling	...	Good	...	253
316Ti	S31635	...	...	Hot saturated	Cold	...	Resistant	...	253
316Ti	S31635	...	...	Hot saturated	Boiling	...	Good	...	253
317L	S31703	...	...	Hot saturated	Cold	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Bitartrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	Hot saturated	Boiling	...	Good	...	253
317LN	S31725	...	...	Hot saturated	Cold	...	Resistant	...	253
317LN	S31725	...	...	Hot saturated	Boiling	...	Good	...	253
321	S32100	...	...	Hot saturated	Cold	...	Resistant	...	253
321	S32100	...	...	Hot saturated	Boiling	...	Questionable	...	253
329	S32900	...	...	Hot saturated	Cold	...	Resistant	...	253
329	S32900	...	...	Hot saturated	Boiling	...	Good	...	253
347	S34700	...	...	Hot saturated	Cold	...	Resistant	...	253
347	S34700	...	...	Hot saturated	Boiling	...	Questionable	...	253
434	S43400	...	...	Hot saturated	Boiling	...	Questionable	...	253
F51	S31803	...	...	Hot saturated	Cold	...	Resistant	...	253
F51	S31803	...	...	Hot saturated	Boiling	...	Good	...	253

Potassium Bromide

Potassium bromide, KBr, is a white crystalline hygroscopic solid that has a melting point of 730 °C (1346 °F). It has a bitter taste and is soluble in water. Potassium bromide is used in manufacturing photographic paper, soaps, and in medicine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Potassium bromide solutions reacted with aluminum alloys during tests at ambient temperature.

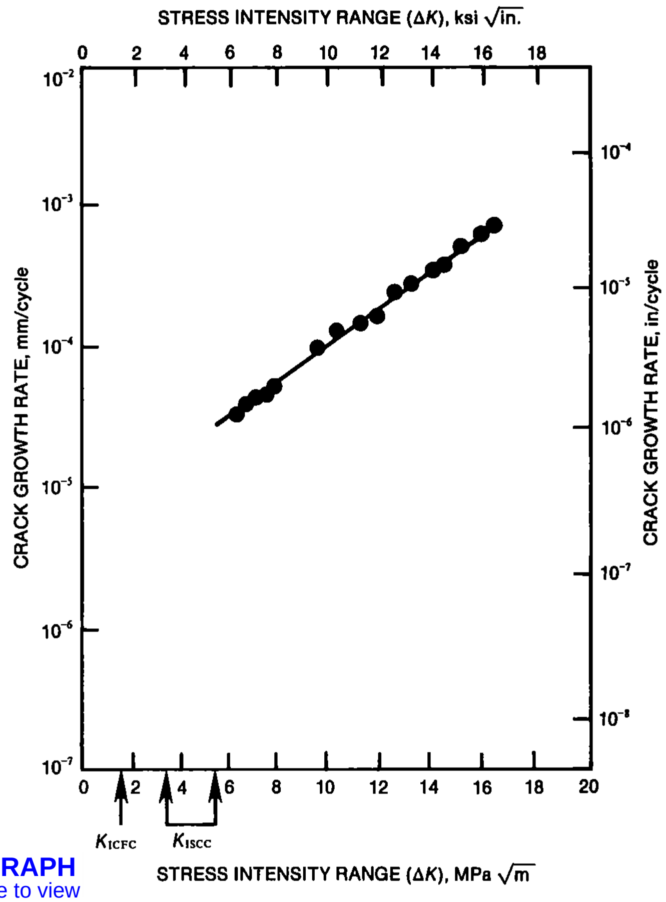
Corrosion Behavior of Various Metals and Alloys in Potassium Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	760 (1400)	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	200-400 (390-750)	...	0.05 (2) max	...	9
Nickel and alloys									
Alloy 825	N08825	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus dissolved ammonia, pH 8-9.5 (filter)	Saturated	85 (185)	20 d	0.003 (0.1) max	...	89
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Bromide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 25% potassium bromate, 1.5% potassium hydroxide, bromine, trace iron	75	18 (65)	3.4 d	0.20 (7.8)	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus dissolved ammonia, pH 8-9.5 (filter)	Saturated	85 (185)	20 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 25% potassium bromate, 1.5% potassium hydroxide, bromine, trace iron	75	18 (65)	3.4 d	0.14 (5.7)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus dissolved ammonia, pH 8-9.5 (filter)	Saturated	85 (185)	20 d	0.003 (0.1) max	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
410	S41000	...	...	...	Room	...	Good	...	121
430	S43000	...	...	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	...	20 (68)	...	Resistant	Pitting	253
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus dissolved ammonia, pH 8-9.5 (filter)	Saturated	85 (185)	20 d	0.003 (0.1) max	...	89
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253



LIVE GRAPH
Click here to view

Aluminum. Corrosion fatigue behavior of aluminum alloy 7079-T651 plate (S-L orientation). Temperature: 23 °C (73 °F); frequency: 4 cycle/s; stress ratio: $R = 0$. Source: M.O. Speidel, M.J. Blackburn, T.R. Beck, and J.Q. Feeney, "Corrosion Fatigue and Stress Corrosion Crack Growth in High Strength Aluminum Alloys, Magnesium Alloys and Titanium Alloys Exposed to Aqueous Solutions," in *Corrosion Fatigue: Chemistry, Mechanics and Microstructure*, O. Devereux, A.J. McEvily, and R.W. Staehle, Ed., National Association of Corrosion Engineers, Houston, 1973, 324-345.

Potassium Carbonate

Also known as potash and salt of tartar, K_2CO_3 is white, water soluble, deliquescent powder, that melts at 891 °C, and is insoluble in alcohol. Used in brewing, ceramics, explosives, fertilizers, and as a chemical intermediate.

Corrosion Behavior of Various Metals and Alloys in Potassium Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Carbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	...	...	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
303	S30300	...	...	...	...	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	...	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	...	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	...	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	...	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	...	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	...	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	...	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	...	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	...	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	...	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Good	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Good	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Carbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	...	Boiling	...	Good	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Good	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Good	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Good	...	253
420	S42000	...	...	...	...	...	Good	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	...	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	...	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	...	...	Resistant	...	253

Potassium Chlorate

Potassium chlorate, $KClO_3$, is transparent, colorless crystals or a white powder that is soluble in water, alcohol, and alkalies, and has a melting point of 356 °C. Used as an oxidizing agent, for explosives and matches, and in textile printing and paper manufacture.

Corrosion Behavior of Various Metals and Alloys in Potassium Chlorate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Chlorate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Resistant	...	253
420	S42000	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Potassium Chloride

Potassium chloride, KCl, also known as potassium muriate and sylvite, is a colorless crystalline solid with a salty taste that melts at 776 °C (1420 °F). It is soluble in water, but insoluble in alcohol. Potassium chloride is used in fertilizers, pharmaceuticals, photography, and as a salt substitute.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Tested under laboratory conditions of ambient temperature and 100% relative humidity, aluminum alloys 3003 and 5154 resisted solid potassium chloride. Aluminum alloy hopper cars have been used to ship granular potassium chloride.

Copper. Aluminum bronzes are generally suitable for servicing potassium chloride.

Corrosion Behavior of Various Metals and Alloys in Potassium Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	96
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead	L50045	...	...	0.25-8.0	8 (47)	...	0.5 (20) max	...	95
Tin	...	...	...	...	20 (35)	...	Resistant	Pitting possible	94
Tin	...	...	...	...	30 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Titanium	...	...	...	Saturated	60 (140)	...	Resistant	...	90
Titanium, grade 12	R53400	...	Tight crevices pH 3.0.	10	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 3.0.	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 3.0.	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 3.0.	10	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	Tight crevices pH 3.0.	10	Boiling	...	Resistant	...	215
Zr702	R60702	...	...	Saturated	60 (140)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	Saturated	Room	...	0.025 (1) max	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated	Boiling	...	Good	Pitting	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	Pitting	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Trace copper.	25	21 (70)	64 d	0.005 (0.2)	Moderate pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Saturated solution, 2-7 g/L potassium hydroxide, 2-3 g/L potassium sulfate, 1 g/L potassium carbonate, 3.5 ppm calcium, specific gravity 1.18, pH 13.5	28	65 (150)	215 d	0.003 (0.1) max	Crevice attack	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% sodiium sulfate, 0.05% sodium chloride, lead, copper, trace starch, pH 9-10 (Dorr clariflocculator, overflow weir)	31.5	82 (180)	65 d	0.005 (0.2)	Severe pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 13.95% potassium ion, 13.49% chloride ion, 0.59% sodium ion, 0.5% sulfate ion, 0.29% ferric oxide, 0.07% calcium ion, trace copper powder, 210 ppm amine acetate	~25	50 (122)	29 d	0.008 (0.3)	Crevice attack	89
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	Saturated	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	Pitting	253
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Trace copper	25	21 (70)	64 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Saturated solution, 2-7 g/L potassium hydroxide, 2-3 g/L potassium sulfate, 1 g/L potassium carbonate, 3.5 ppm calcium, specific gravity 1.18, pH 13.5	28	65 (150)	215 d	0.003 (0.1) max	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 0.5% sodium sulfate, 0.05% sodium chloride, lead, copper, trace starch, pH 9-10 (Dorr clariflocculator, overflow weir)	31.5	82 (180)	65 d	0.005 (0.2)	...	89121
316	S31600	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 13.95% potassium ion, 13.49% chloride ion, 0.59% sodium ion, 0.5% sulfate ion, 0.29% ferric oxide, 0.07% calcium ion, trace copper powder, 210 ppm amine acetate	~25	50 (122)	29 d	0.003 (0.1) max	Crevice attack	89
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	Pitting	253
403	S40300	...	...	...	20 (68)	...	Good	Pitting	253
403	S40300	...	...	Saturated	Boiling	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Good	Pitting	253
405	S40500	...	...	Saturated	Boiling	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	Saturated	Boiling	...	Poor	Pitting	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	...	20 (68)	...	Good	Pitting	253
410	S41000	...	...	Saturated	Boiling	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Good	Pitting	253
416	S41600	...	...	Saturated	Boiling	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Good	Pitting	253
420	S42000	...	...	Saturated	Boiling	...	Poor	Pitting	253
430	S43000	...	...	10	21 (70)	...	Good	...	93
430	S43000	...	...	...	20 (68)	...	Resistant	Pitting	253
430	S43000	...	...	Saturated	Boiling	...	Good	Pitting	253
434	S43400	...	...	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	Pitting	253
AM-363	S36300	...	...	...	Room	...	Poor	...	120
Carpenter 20	...	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Saturated solution, 2-7 g/L potassium hydroxide, 2-3 g/L potassium sulfate, 1 g/L potassium carbonate, 3.5 ppm calcium, specific gravity 1.18, pH 13.5	28	65 (150)	215 d	0.003 (0.1) max	...	89
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	Pitting	253

Potassium Chromium Sulfate

Also known as chrome alum and chrome potash alum, $CrK(SO_4)_2 \cdot 12H_2O$ is dark, violet-red crystals that are efflorescent and soluble in water. Derived by reducing potassium dichromate in dilute sulfuric acid with sulfurous acid. Used in tanning (chrome-tan liquors), textile dye (mordant), photography (fixing bath) and ceramics.

Corrosion Behavior of Various Metals and Alloys in Potassium Chromium Sulfate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Poor	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Poor	...	253
303	S30300	...	...	...	20 (68)	...	Questionable	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Poor	...	253
303	S30300	...	...	...	Boiling	...	Poor	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Chromium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Poor	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Poor	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Poor	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Poor	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Poor	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Poor	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Poor	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Poor	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Poor	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Poor	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Poor	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Poor	...	253
403	S40300	...	...	...	20 (68)	...	Questionable	...	253
403	S40300	...	...	...	Boiling	...	Poor	...	253
405	S40500	...	...	...	20 (68)	...	Questionable	...	253
405	S40500	...	...	...	Boiling	...	Poor	...	253
409	S40900	...	...	...	20 (68)	...	Questionable	...	253
409	S40900	...	...	...	Boiling	...	Poor	...	253
410	S41000	...	...	...	20 (68)	...	Questionable	...	253
410	S41000	...	...	...	Boiling	...	Poor	...	253
416	S41600	...	...	...	20 (68)	...	Questionable	...	253
416	S41600	...	...	...	Boiling	...	Poor	...	253
420	S42000	...	...	...	20 (68)	...	Questionable	...	253
420	S42000	...	...	...	Boiling	...	Poor	...	253
430	S43000	...	...	...	20 (68)	...	Questionable	...	253
430	S43000	...	...	...	Boiling	...	Poor	...	253
434	S43400	...	...	...	20 (68)	...	Good	...	253
434	S43400	...	...	...	Boiling	...	Poor	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Poor	...	253

Potassium Cyanate

Potassium cyanate. KOCN, is colorless, water soluble crystals. Used as an herbicide and for the manufacture of drugs and organic chemicals.

Corrosion Behavior of Various Metals and Alloys in Potassium Cyanate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Potassium Cyanide

Potassium cyanide, KCN, is poisonous, white, deliquescent crystals with a bitter almond taste, that is soluble in water, alcohol, and glycerol. Used for metal extraction, for electroplating, for heat-treating steel, and as an analytical reagent and insecticide.

Corrosion Behavior of Various Metals and Alloys in Potassium Cyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
303	S30300	...	...	5	20 (68)	...	Resistant	...	253
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Cyanide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	...	5	20 (68)	...	Resistant	...	253
405	S40500	...	...	5	20 (68)	...	Resistant	...	253
409	S40900	...	...	5	20 (68)	...	Resistant	...	253
410	S41000	...	...	5	20 (68)	...	Resistant	...	253
416	S41600	...	...	5	20 (68)	...	Resistant	...	253
420	S42000	...	...	5	20 (68)	...	Resistant	...	253
430	S43000	...	...	5	20 (68)	...	Resistant	...	253
434	S43400	...	...	5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253

Potassium Dichromate

Also known as potassium bichromate and red potassium chromate, $K_2Cr_2O_7$ is poisonous, yellowish-red crystals with a metallic taste that is soluble in water, insoluble in alcohol, that melt at 396 °C and decompose at 500 °C. Used as an oxidizing agent and analytical reagent, and in explosives, matches, and electroplating.

Corrosion Behavior of Various Metals and Alloys in Potassium Dichromate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	25	20 (68)	...	Resistant	...	253
301	S30100	...	...	25	Boiling	...	Resistant	...	253
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Resistant	...	253
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Resistant	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Resistant	...	253
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Resistant	...	253
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Resistant	...	253
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Resistant	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Resistant	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Dichromate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Resistant	...	253
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Resistant	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Resistant	...	253
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Resistant	...	253
403	S40300	...	...	25	20 (68)	...	Resistant	...	253
403	S40300	...	...	25	Boiling	...	Poor	...	253
405	S40500	...	...	25	20 (68)	...	Resistant	...	253
405	S40500	...	...	25	Boiling	...	Poor	...	253
409	S40900	...	...	25	20 (68)	...	Resistant	...	253
409	S40900	...	...	25	Boiling	...	Poor	...	253
410	S41000	...	...	25	20 (68)	...	Resistant	...	253
410	S41000	...	...	25	Boiling	...	Poor	...	253
416	S41600	...	...	25	20 (68)	...	Resistant	...	253
416	S41600	...	...	25	Boiling	...	Poor	...	253
420	S42000	...	...	25	20 (68)	...	Resistant	...	253
420	S42000	...	...	25	Boiling	...	Poor	...	253
430	S43000	...	...	25	20 (68)	...	Resistant	...	253
430	S43000	...	...	25	Boiling	...	Resistant	...	253
434	S43400	...	...	25	20 (68)	...	Resistant	...	253
434	S43400	...	...	25	Boiling	...	Resistant	...	253
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253
F51	S31803	...	...	25	Boiling	...	Resistant	...	253

Potassium Difluoride

Also known as potassium acid fluoride and potassium hydrogen fluoride, KHF_2, is colorless crystals that decompose when heated. Soluble in alcohol and water. Used for etching glass, flux and silver solder, electrolyte in fluorine production.

Corrosion Behavior of Various Metals and Alloys in Potassium Difluoride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Questionable	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Difluoride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	20 (68)	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Poor	...	253
410	S41000	...	...	Saturated	20 (68)	...	Poor	...	253
416	S41600	...	...	Saturated	20 (68)	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Poor	...	253
430	S43000	...	...	Saturated	20 (68)	...	Questionable	...	253
434	S43400	...	...	Saturated	20 (68)	...	Good	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253

Potassium Ferricyanide

Also known as red potassium prussiate and red prussiate of potash, $K_3Fe(CN)_6$ is poisonous, bright red, water-soluble crystals that decompose when heated. Used in calico printing and wool dyeing.

Corrosion Behavior of Various Metals and Alloys in Potassium Ferricyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Ferricyanide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Potassium Ferrocyanide

Also known as yellow prussiate of potash, $K_4Fe(CN)_6 \cdot 3H_2O$ is yellow crystals with a saline taste that are soluble in water, insoluble in alcohol and loses water at 60 °C. Used in medicine, dry colors, explosives, and as an analytical reagent.

Corrosion Behavior of Various Metals and Alloys in Potassium Ferrocyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Ferrocyanide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Potassium Fluoride

Potassium fluoride, KF, is a colorless, deliquescent crystalline solid that has a melting point of 846 °C (1550 °F). Potassium fluoride has a salty taste and is poisonous. It is soluble in water, but insoluble in alcohol. Potassium fluoride is used in etching glass, preservatives, and insecticides.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Zirconium. Zirconium has good resistance to potassium fluoride at low temperatures, but resistance drops rapidly as the temperature is increased.

Corrosion Behavior of Various Metals and Alloys in Potassium Fluoride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Refractory metals and alloys									
Zr702	R60702	...	pH 8.9	20	28 (82)	...	Resistant	...	15
Zr702	R60702	...	pH 8.9	20	90 (185)	...	1.3 (50) min	...	15
Zr702	R60702	...	...	0.3	Boiling	...	0.025 (1) max	...	15

Potassium Hydroxide

Potassium hydroxide, KOH, also known as caustic potash, lye, and potassium hydrate, is a white deliquescent crystalline solid that has a melting point of 360 °C (680 °F). It is soluble in water and alcohol. Potassium hydroxide is used as a mordant, mercerizing agent, in medicine, and in manufacturing soap and matches. It is a powerful cleansing bath for scouring metals and when used in steel-quenching baths gives a higher quenching rate than water alone without attacking the steel as a salt solution would. Potassium hydroxide is slightly more aggressive in the corrosion of metals and nonmetals than sodium hydroxide, but this may be due to its higher boiling point and likelihood of higher temperature exposure. Nickel alloys have been reported to be less sensitive to stress cracking in potassium hydroxide than in sodium hydroxide.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Potassium hydroxide is very corrosive to all aluminum alloys.

Copper. Aluminum bronzes are generally suitable for service in potassium hydroxide.

Nickel. Nickel 200 and 201 are used in the production of all concentrations and temperatures (including the molten stage) of potassium hydroxide. At temperatures exceeding 315 °C (600 °F), the lower carbon nickel 201 is used to avoid graphite precipitation. In situations where the dilute potassium hydroxide is evaporated to 50% concentration and contaminants such as chlorates and chlorides may be present, nickel 200 is extensively used. These contaminants can increase corrosion rates especially under velocity conditions. The resistance to corrosion and stress-corrosion cracking of nickel alloys increases with increasing nickel content, and alloys 400, 600, and C-276 may be used in situations requiring higher strength and resistance to other corrosive agents. However, these alloys can be attacked at higher temperatures and concentrations of potassium hydroxide.

Niobium. Niobium is embrittled at low concentrations (5%) of potassium hydroxide above room temperature.

Silver. Silver is not attacked at temperatures slightly below 500 °C (930 °F) by potassium hydroxide.

Iridium. Iridium is slightly attacked by potassium hydroxide.

Osmium. Osmium is attacked by potassium hydroxide.

Tantalum. Although tantalum is not dissolved by potassium hydroxide, the metal is destroyed by the continuous formation of surface scale layers. The rate of scale formation increases with concentration and temperature. Tantalum anode baskets have been successfully used in silver cyanide barrel platers, although the alkaline solutions contain potassium hydroxide. The positive voltage of the cell itself protected the tantalum anode basket from surface scale formation. Tantalum-tungsten alloys showed little improvement over tantalum when tested in a potassium hydroxide/potassium ferrocyanide mixture.

Titanium. Titanium alloys have low corrosion rates in potassium hydroxide solutions at sub-boiling temperatures. However, the corrosion rate increases significantly with higher temperatures and concentrations. Titanium alloys can experience hydrogen buildup and eventual embrittlement in potassium hydroxide solutions when temperatures exceed 80 °C (175 °F) and the pH is 12 or more. The addition of dissolved oxidizing compounds such as chlorates or hypochlorites to hot caustic solutions can extend the hydrogen resistance of titanium to somewhat higher temperatures.

Zirconium. Zirconium is fairly resistant to potassium hydroxide.

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Low-carbon steel	G10100	...	...	50	25 (80)	207 d	0.003 (0.1) max	...	111
Low-carbon steel	G10100	...	Plus 13% KCI. Slight attack under spacer	13	30 (85)	207 d	0.013 (0.5)	...	111
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	0-50	24-60 (75-140)	...	0.5 (20) max	...	95
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Platnium	P04995	...	...	All	300 (570)	...	0.05 (2) max	...	5
Platnium	P04995	...	Melt. Pt is attacked if strong oxidizers are present	...	300 (570)	...	0.05 (2) max	...	5
Silver	P07010	...	Air must be excluded	All	300 (570)	...	0.05 (2) max	...	9
Silver	P07010	...	Melt. Air must be excluded	...	350 (680)	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Inconel 600	N06600	...	...	50	25 (80)	207 d	Resistant	...	111
Inconel 600	N06600	...	Plus 13% KCI	13	30 (85)	207 d	Resistant	...	111
Monel 400	N04400	...	...	50	25 (80)	207 d	0.003 (0.1) max	...	111
Monel 400	N04400	...	Plus 13% KCI	13	30 (85)	207 d	Resistant	...	111
Nickel 200	N02200	...	...	50	25 (80)	207 d	0.003 (0.1) max	...	111
Nickel 200	N02200	...	Plus 13% KCI	13	30 (85)	207 d	Resistant	...	111
Nickel 200	N02200	...	Saturated with KCI, 0.05% potassium chlorate. Liquid	30	Boiling	...	0.005 (0.2)	...	44
Nickel 200	N02200	...	Saturated with KCI, 0.05% potassium chlorate. Vapor	30	Boiling	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Saturated with KCI, 0.078% potassium chlorate. Liquid	47	Boiling	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Saturated with KCI, 0.078% potassium chlorate. Vapor	47	Boiling	...	0.008 (0.3)	...	44
Nickel 200	N02200	...	Velocity 21.6 ft/min	70	149 (300)	...	0.01 (0.4)	...	44
Nickel 200	N02200	...	Velocity 348 ft/min	70	149 (300)	...	0.04 (1.6)	...	44
Refractory metals and alloys									
Hafnium	...	...	...	50	...	2 d	0.01 (0.5)	...	11

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium	R04210	...	...	5-40	Room	...	Questionable	...	2
Niobium	R04210	...	...	1-5	98 (208)	...	Questionable	...	2
Titanium	...	...	...	10	Boiling	...	0.13 (5)	...	1
Titanium	...	...	...	10	Boiling	...	0.13 (5.1) max	...	90
Titanium	...	...	...	25	Boiling	...	0.3 (12)	...	1
Titanium	...	...	...	25	Boiling	...	0.31 (12)	...	90
Titanium	...	...	...	50	24 (75)	...	0.010 (0.4)	...	1
Titanium	...	...	...	50	27 (80)	207 d	0.01 (0.4)	...	111
Titanium	...	...	...	50	29 (85)	...	0.010 (0.4)	...	90
Titanium	...	...	...	50	150 (302)	...	2.7 (108)	...	91
Titanium	...	...	...	50	Boiling	...	27 (106)	...	1
Titanium	...	...	...	50	Boiling	...	2.74 (110)	...	90
Titanium	...	...	Anhydrous	50	241-377 (467-712)	...	1.5 (61) max	...	90
Titanium	...	...	Plus 13% KCI	13	29 (85)	...	Resistant	...	90
Titanium	...	...	Plus 13% KCI	13	29 (85)	207 d	0.02 (0.9)	...	111
Titanium, grade 9	...	...	...	50	150 (302)	...	9.2 (362)	...	33
Titanium, grade 9	...	...	...	50	150 (302)	...	9.1 (363)	...	91
Zirconium	R60701	...	...	50	27 (80)	207 d	0.0015 (0.06)	...	111
Zirconium	R60701	...	Plus 13% KCI	13	30 (85)	207 d	0.005 (0.2)	...	111
Zr702	R60702	...	...	50	27 (80)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	10	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	25	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	50	Boiling	...	0.13 (5) max	...	15
Zr702	R60702	...	Plus 13% KCI	13	29 (85)	...	0.025 (1) max	...	15
Zr702	R60702	...	To anhydrous	50	241-377 (465-710)	...	1.3 (50) min	...	15
Stainless steels									
301	S30100	...	...	20	20 (68)	...	Resistant	...	253
301	S30100	...	...	20	Boiling	...	Resistant	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Resistant	...	253
301	S30100	...	...	Hot saturated	Boiling	...	Resistant	...	253
301	S30100	...	...	Fused	360 (680)	...	Poor	...	253
302	S30200	...	...	20	20 (68)	...	Resistant	...	253
302	S30200	...	...	20	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	...	Hot saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Fused	360 (680)	...	Poor	...	253
303	S30300	...	...	20	20 (68)	...	Resistant	...	253
303	S30300	...	...	20	20 (68)	...	Resistant	...	253
303	S30300	...	...	20	Boiling	...	Resistant	...	253
303	S30300	...	...	20	Boiling	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Good	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	Hot saturated	Boiling	...	Good	...	253
303	S30300	...	...	Hot saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Fused	360 (680)	...	Poor	...	253
303	S30300	...	...	Fused	360 (680)	...	Poor	...	253
304	S30400	...	...	20	20 (68)	...	Resistant	...	253
304	S30400	...	...	20	Boiling	...	Resistant	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	Hot saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Fused	360 (680)	...	Poor	...	253
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Plus isopropanol solution of hexachlorocyclopentadiene	20	80 (176)	146 d	0.005 (0.2)	Slight pitting	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus isopropanol solution of hexachlorocyclopentadiene	20	80 (176)	90 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; no agitation. Plus 50% sodium hydroxide	50	93 (200) max	30 d	.003 (0.1) max	...	89
304	S30400	...	No aeration; rapid agitation. Plus 21.6% sodium hydroxide, approx. 3% ammonium hydroxide (evaporator)	32.4	120 (248)	60 d	0.58 (23)	...	89
304	S30400	...	No aeration; rapid agitation. Plus 21.6% sodium hydroxide, approx. 3% ammonium hydroxide (evaporator)	32.4	120 (248)	60 d	0.55 (22)	...	89
304	S30400	...	No aeration; rapid agitation. Plus 37.8% potassium isobutyrate, 5.5% potassium sulfide, 2.1% potassium carbonate, 1.9% potassium mercaptides (reboiler)	25.2	139-142 (282-290)	140 d	Poor	...	89
304	S30400	...	No aeration; rapid agitation. With carbon over the standard maximum. Plus 37.8% potassium isobutyrate, 5.5% potassium sulfide, 2.1% potassium carbonate, 1.9% potassium mercaptides (reboiler)	25.2	139-142 (282-290)	140 d	Poor	...	89
304	S30400	...	No agitation	~80	Boiling	4 d	2.5 (100)	...	89
304	S30400	...	Petroleum processing; field or pilot plant test; slight to moderate aeration; rapid agitation. Plus 28% alkyl phenolate, 19% potassium isobutyrate, 0.8% sulfide, 0.4% mercaptans (bottom of "solutizer" regenerator tower)	11.2	182-193 (360-380)	276 d	0.06 (2.3)	Slight pitting. Crevice attack	89
304	S30400	...	Petroleum processing; field or pilot plant test; slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Plus 28% alkyl phenolate, 19% potassium isobutyrate, 0.8% sulfide, 0.4% mercaptans (bottom of "solutizer" regenerator tower)	11.2	182-193 (360-380)	276 d	0.06 (2.4)	Slight pitting. Crevice attack	89
304	S30400	...	Rapid agitation	~50	Boiling	3 d	3.3 (130)	...	89
304	S30400	...	Rapid agitation	90-92	380 (716)	4 d	8.8 (350)	...	89
304	S30400	...	Slight to moderate aeration; no agitation. With carbon over the standard maximum. Plus isopropanol solution of hexachloropentadiene (vapors)	20	94 (202)	18 d	.01 (0.4)	Slight pitting	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Plus isopropanol solution of hexachloropentadiene	20	94 (202)	19 d	.02 (0.9)	Slight pitting	89
304L	S30403	...	...	20	20 (68)	...	Resistant	...	253
304L	S30403	...	...	20	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304L	S30403	...	...	Hot saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Fused	360 (680)	...	Poor	...	253
304LN	S30453	...	...	20	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	20	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Hot saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Fused	360 (680)	...	Poor	...	253
316	S31600	...	...	20	20 (68)	...	Resistant	...	253
316	S31600	...	...	20	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	Hot saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Fused	360 (680)	...	Poor	...	253
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; no agitation. Plus 50% sodium hydroxide	50	93 (200) max	30 d	0.003 (0.1) max	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 21.6% sodium hydroxide, approx. 3% ammonium hydroxide (evaporator)	32.4	120 (248)	60 d	0.7 (29)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no agitation	~80	Boiling	4 d	0.20 (8)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; rapid agitation	~50	Boiling	3 d	3.05 (120)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; rapid agitation	90-92	380 (716)	4 d	6.35 (250)	...	89
316	S31600	...	No aeration; rapid agitation. Plus 21.6% sodium hydroxide, approx. 3% ammonium hydroxide (evaporator)	32.4	120 (248)	60 d	.75 (30)	...	89
316	S31600	...	Slight to moderate aeration; no agitation. Plus isopropanol solution of hexachloropentadiene (vapors)	20	94 (202)	18 d	.008 (0.3)	Slight pitting	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus 28% alkyl phenolate, 19% potassium isobutyrate, 0.8% sulfide, 0.4% mercaptans (bottom of "solutizer" regenerator tower)	11.2	182-193 (360-380)	276 d	0.10 (4.1)	Slight pitting. Crevice attack	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus isopropanol solution of hexachlorocyclopentadiene	20	80 (176)	146 d	.005 (0.2)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31500	...	Slight to moderate aeration; rapid agitation. Plus isopropanol solution of hexachloropentadiene	20	94 (202)	19 d	.018 (0.7)	Slight pitting	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Plus isopropanol solution of hexachloropentadiene	20	80 (176)	90 d	.003 (0.1)	...	89
316F	S31620	...	...	20	20 (68)	...	Resistant	...	253
316F	S31620	...	...	20	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316F	S31620	...	...	Hot saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Fused	360 (680)	...	Poor	...	253
316L	S31603	...	...	20	20 (68)	...	Resistant	...	253
316L	S31603	...	...	20	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	Hot saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Fused	360 (680)	...	Poor	...	253
316LN	S31653	...	...	20	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	20	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Hot saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Fused	360 (680)	...	Poor	...	253
316Ti	S31635	...	...	20	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	20	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Hot saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Fused	360 (680)	...	Poor	...	253
317L	S31703	...	...	20	20 (68)	...	Resistant	...	253
317L	S31703	...	...	20	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	Hot saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Fused	360 (680)	...	Poor	...	253
317LN	S31725	...	...	20	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	20	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Hot saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Fused	360 (680)	...	Poor	...	253
321	S32100	...	...	20	20 (68)	...	Resistant	...	253
321	S32100	...	...	20	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	...	Hot saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Fused	360 (680)	...	Poor	...	253
329	S32900	...	...	20	20 (68)	...	Resistant	...	253
329	S32900	...	...	20	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	Hot saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Fused	360 (680)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	...	20	20 (68)	...	Resistant	...	253
347	S34700	...	...	20	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	...	Hot saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Fused	360 (680)	...	Poor	...	253
403	S40300	...	...	20	20 (68)	...	Resistant	...	253
403	S40300	...	...	20	Boiling	...	Resistant	...	253
403	S40300	...	...	50	20 (68)	...	Resistant	...	253
403	S40300	...	...	50	Boiling	...	Questionable	...	253
403	S40300	...	...	Hot saturated	Boiling	...	Questionable	...	253
403	S40300	...	...	Fused	360 (680)	...	Poor	...	253
405	S40500	...	...	20	20 (68)	...	Resistant	...	253
405	S40500	...	...	20	Boiling	...	Resistant	...	253
405	S40500	...	...	50	20 (68)	...	Resistant	...	253
405	S40500	...	...	50	Boiling	...	Questionable	...	253
405	S40500	...	...	Hot saturated	Boiling	...	Questionable	...	253
405	S40500	...	...	Fused	360 (680)	...	Poor	...	253
409	S40900	...	...	20	20 (68)	...	Resistant	...	253
409	S40900	...	...	20	Boiling	...	Resistant	...	253
409	S40900	...	...	50	20 (68)	...	Resistant	...	253
409	S40900	...	...	50	Boiling	...	Questionable	...	253
409	S40900	...	...	Hot saturated	Boiling	...	Questionable	...	253
409	S40900	...	...	Fused	360 (680)	...	Poor	...	253
410	S41000	...	...	20	20 (68)	...	Resistant	...	253
410	S41000	...	...	20	Boiling	...	Resistant	...	253
410	S41000	...	...	50	20 (68)	...	Resistant	...	253
410	S41000	...	...	50	Boiling	...	Questionable	...	253
410	S41000	...	...	Hot saturated	Boiling	...	Questionable	...	253
410	S41000	...	...	Fused	360 (680)	...	Poor	...	253
416	S41600	...	...	20	20 (68)	...	Resistant	...	253
416	S41600	...	...	20	Boiling	...	Resistant	...	253
416	S41600	...	...	50	20 (68)	...	Resistant	...	253
416	S41600	...	...	50	Boiling	...	Questionable	...	253
416	S41600	...	...	Hot saturated	Boiling	...	Questionable	...	253
416	S41600	...	...	Fused	360 (680)	...	Poor	...	253
420	S42000	...	...	20	20 (68)	...	Resistant	...	253
420	S42000	...	...	20	Boiling	...	Resistant	...	253
420	S42000	...	...	50	20 (68)	...	Resistant	...	253
420	S42000	...	...	50	Boiling	...	Questionable	...	253
420	S42000	...	...	Hot saturated	Boiling	...	Questionable	...	253
420	S42000	...	...	Fused	360 (680)	...	Poor	...	253
430	S43000	...	...	20	20 (68)	...	Resistant	...	253
430	S43000	...	...	20	Boiling	...	Resistant	...	253
430	S43000	...	...	50	20 (68)	...	Resistant	...	253
430	S43000	...	...	50	Boiling	...	Good	...	253
430	S43000	...	...	Hot saturated	Boiling	...	Good	...	253
430	S43000	...	...	Fused	360 (680)	...	Poor	...	253
434	S43400	...	...	20	20 (68)	...	Resistant	...	253
434	S43400	...	...	20	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Resistant	...	253
434	S43400	...	...	Hot saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Fused	360 (680)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Hydroxide (Continued)

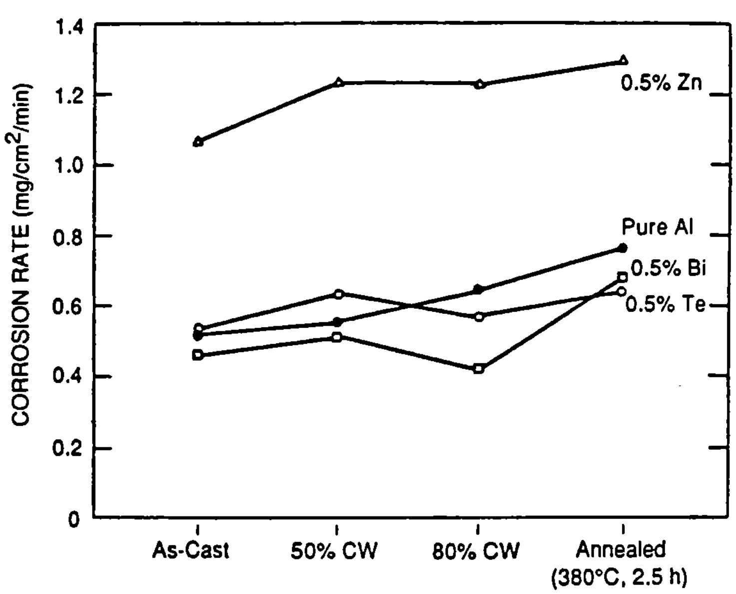
Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	Chemical processing; field or pilot plant test; no agitation	~80	Boiling	4 d	0.51 (20)	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; rapid agitation	~50	Boiling	3 d	3.81 (150)	...	89
Carpenter 20	...	...	Chemical processing; field or pilot plant test; rapid agitation; cast specimens	92-98	380 (716)	4 d	2.34 (92)	...	89
F51	S31803	...	...	20	20 (68)	...	Resistant	...	253
F51	S31803	...	...	20	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253
F51	S31803	...	...	Hot saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Fused	360 (680)	...	Poor	...	253

Corrosion of Metals and Alloys in Potassium Hydroxide Solutions

Material	Corrosion rate 13% KOH(a) mm/yr	mils/yr	50% KOH(b) mm/yr	mils/yr
Titanium	0.023	0.9	0.01	0.4
Zirconium	0.005	0.2	0.0015	0.06
Nickel	nil		0.00008	0.003
Monel	nil		0.00005	0.002
Inconel	nil		nil	
Low-carbon steel	0.013	0.5(c)	0.0013	0.05

(a) 207-day test at 30 °C (85 °F); 13% KCl added to solution. (b) 207-day test at 25 °C (80 °F). (c) Slight attack under spacer. Source: Ref 62

Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1178.



Various alloys. Average corrosion rate as a function of cold work for pure Al and Al-Zn, Al-Bi, and Al-Te binary alloys in 4M Potassium Hydroxide solution at 50 °C (122 °F). Ref. 261

Potassium Hypochlorite

Also known as eau de Javelle, KOCl is known only in solution, and is formed by passing chlorine through a solution of potassium hydroxide. The aqueous solution is strongly oxidizing, and is used as a bleach.

Corrosion Behavior of Various Metals and Alloys in Potassium Hypochlorite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Questionable	Pitting	253
301	S30100	...	...	...	150 (302)	...	Questionable	Pitting	253
302	S30200	...	...	...	20 (68)	...	Questionable	Pitting	253
302	S30200	...	...	...	150 (302)	...	Questionable	Pitting	253
303	S30300	...	...	...	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	...	150 (302)	...	Questionable	Pitting	253
304	S30400	...	...	...	20 (68)	...	Questionable	Pitting	253
304	S30400	...	...	...	150 (302)	...	Questionable	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Questionable	Pitting	253
304L	S30403	...	...	...	150 (302)	...	Questionable	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Questionable	Pitting	253
304LN	S30453	...	...	...	150 (302)	...	Questionable	Pitting	253
316	S31600	...	...	...	20 (68)	...	Good	Pitting	253
316	S31600	...	...	...	150 (302)	...	Good	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Questionable	Pitting	253
316F	S31620	...	...	...	150 (302)	...	Questionable	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	...	150 (302)	...	Good	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	...	150 (302)	...	Good	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	...	150 (302)	...	Good	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	...	150 (302)	...	Good	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	...	150 (302)	...	Good	Pitting	253
321	S32100	...	...	...	20 (68)	...	Questionable	Pitting	253
321	S32100	...	...	...	150 (302)	...	Questionable	Pitting	253
329	S32900	...	...	...	20 (68)	...	Good	Pitting	253
329	S32900	...	...	...	150 (302)	...	Good	Pitting	253
347	S34700	...	...	...	20 (68)	...	Questionable	Pitting	253
347	S34700	...	...	...	150 (302)	...	Questionable	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Good	Pitting	253
F51	S31803	...	...	...	150 (302)	...	Good	Pitting	253

Potassium Iodide

Potassium iodide, KI, is a white crystalline solid that melts at 686 °C (1260 °F). It is soluble in water and alcohol. Potassium iodide is used in analytical chemistry and photography. In medicine, potassium iodide is used to regulate the thyroid gland.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Limited testing of potassium iodide solutions at ambient temperature indicates a corrosion reaction with aluminum alloys comparable to that of sodium chloride.

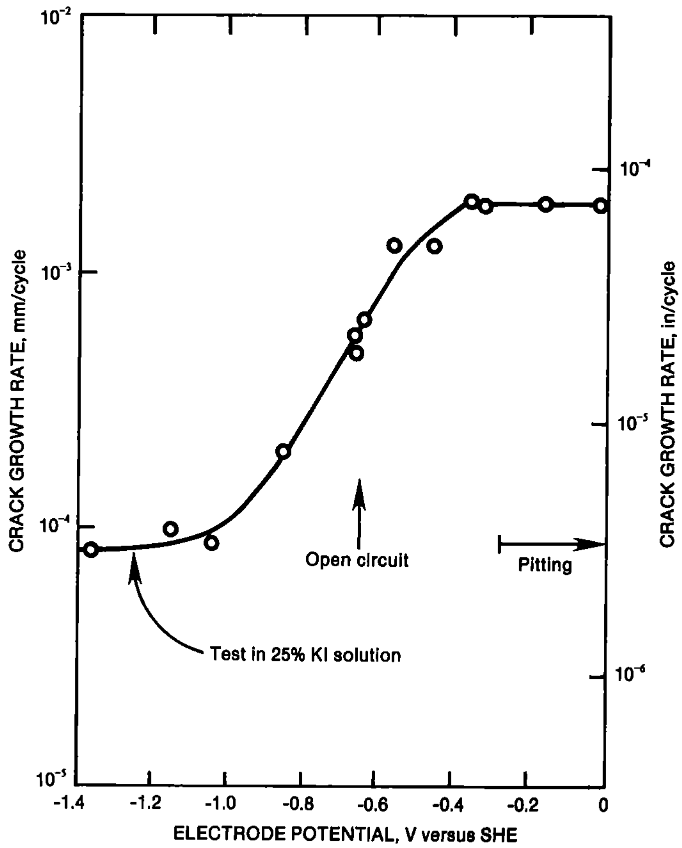
Corrosion Behavior of Various Metals and Alloys in Potassium Iodide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92
Refractory metals and alloys									
Zr702	R60702	...	...	0-70	Room to 100 (212)	...	0.05 (2) max	...	15
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	...	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	...	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	Boiling	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Iodide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	Boiling	...	Resistant	Pitting	253
403	S40300	...	...	...	20 (68)	...	Questionable	Pitting	253
403	S40300	...	...	...	Boiling	...	Questionable	Pitting	253
405	S40500	...	...	...	20 (68)	...	Questionable	Pitting	253
405	S40500	...	...	...	Boiling	...	Questionable	Pitting	253
409	S40900	...	...	...	20 (68)	...	Questionable	Pitting	253
409	S40900	...	...	...	Boiling	...	Questionable	Pitting	253
410	S41000	...	...	...	20 (68)	...	Questionable	Pitting	253
410	S41000	...	...	...	Boiling	...	Questionable	Pitting	253
410	S41000	...	Plus 0.1% sodium carbonate, evaporated to dryness	Saturated	Room	...	Good	...	121
416	S41600	...	...	...	20 (68)	...	Questionable	Pitting	253
416	S41600	...	...	...	Boiling	...	Questionable	Pitting	253
420	S42000	...	...	...	20 (68)	...	Questionable	Pitting	253
420	S42000	...	...	...	Boiling	...	Questionable	Pitting	253
430	S43000	...	...	...	20 (68)	...	Good	Pitting	253
430	S43000	...	...	...	Boiling	...	Good	Pitting	253
434	S43400	...	...	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	...	Boiling	...	Resistant	Pitting	253
AM-363	S36300	...	...	...	Room	...	Good	...	120
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	Boiling	...	Resistant	Pitting	253



Aluminum. Corrosion fatigue behavior of aluminum alloy 7079-T651 plate (S-L orientation) in 25% potassium iodide solution. Temperature: 23 °C (73 °F); frequency: 4 cycles/s; stress ratio: $R = 0$. Source: M.O. Speidel, M.J. Blackburn, T.R. Beck, and J.A. Feeney, "Corrosion Fatigue and Stress Corrosion Crack Growth in High Strength Aluminum Alloys, Magnesium Alloys and Titanium Alloys Exposed to Aqueous Solutions," in *Corrosion Fatigue: Chemistry, Mechanics and Microstructure*, O. Devereux, A.J. McEvily, and R.W. Staehle, Ed., National Association of Corrosion Engineers, Houston, 1973, 324-345.

LIVE GRAPH
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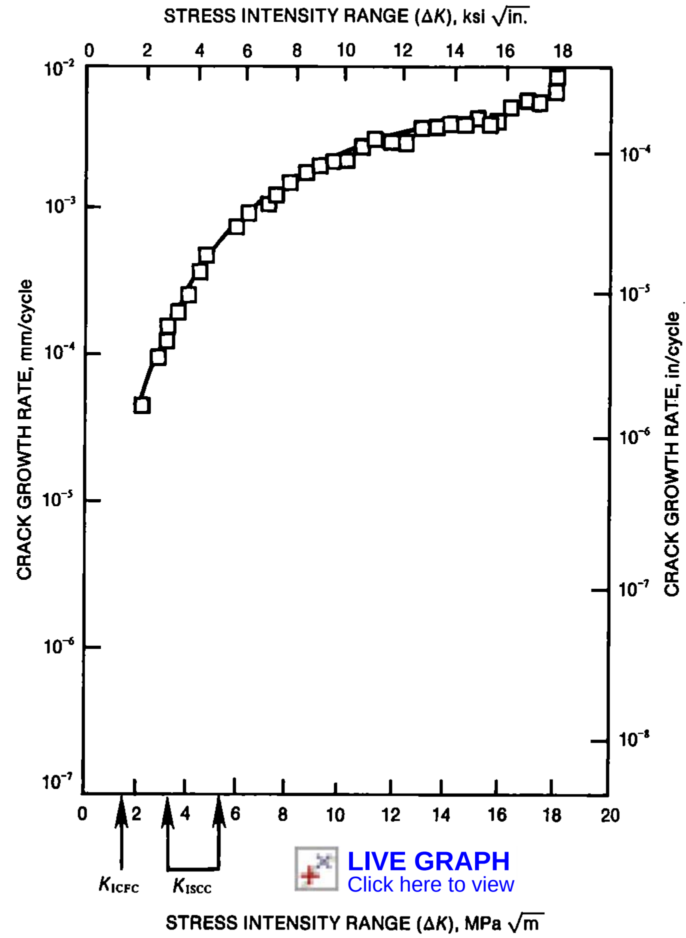


LIVE GRAPH
Click here to view

Aluminum. Corrosion fatigue behavior of aluminum alloy 7079-T651 plate (S-L orientation) in 25% potassium iodide solution. Temperature: 23 °C (73 °F); frequency: 4 cycles/s; stress ratio: $R = 0$. Source: M.O. Speidel, M.J. Blackburn, T.R. Beck, and J.A. Feeney, "Corrosion Fatigue and Stress Corrosion Crack Growth in High Strength Aluminum Alloys, Magnesium Alloys and Titanium Alloys Exposed to Aqueous Solutions," in *Corrosion Fatigue: Chemistry, Mechanics and Microstructure*, O. Devereux, A.J. McEvily, and R.W. Staehle, Ed., National Association of Corrosion Engineers, Houston, 1973, 324-345.

Potassium Nitrate

Also known as niter, KNO_3 is flammable, water-soluble, white crystals with saline taste that melt at 337 °C. Used in pyrotechnics, explosives, and matches, as a fertilizer, and as an analytical reagent.

Corrosion Behavior of Various Metals and Alloys in Potassium Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	25	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	25	Boiling	...	Resistant	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Resistant	...	253
301	S30100	...	Molten	...	550 (1022)	...	Resistant	...	253
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	Molten	...	550 (1022)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	Molten	...	550 (1022)	...	Resistant	...	253
303	S30300	...	Molten	...	550 (1022)	...	Resistant	...	253
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Resistant	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	Molten	...	550 (1022)	...	Resistant	...	253
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304L	S30403	...	Molten	...	550 (1022)	...	Resistant	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	Molten	...	550 (1022)	...	Resistant	...	253
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	Molten	...	550 (1022)	...	Resistant	...	253
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316F	S31620	...	Molten	...	550 (1022)	...	Resistant	...	253
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	Molten	...	550 (1022)	...	Resistant	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	Molten	...	550 (1022)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Nitrate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	Molten	...	550 (1022)	...	Resistant	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	Molten	...	550 (1022)	...	Resistant	...	253
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	Molten	...	550 (1022)	...	Resistant	...	253
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	Molten	...	550 (1022)	...	Resistant	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	Molten	...	550 (1022)	...	Resistant	...	253
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	Molten	...	550 (1022)	...	Resistant	...	253
403	S40300	...	...	25	20 (68)	...	Resistant	...	253
403	S40300	...	...	50	20 (68)	...	Resistant	...	253
403	S40300	...	Molten	...	550 (1022)	...	Poor	...	253
405	S40500	...	...	25	20 (68)	...	Resistant	...	253
405	S40500	...	...	50	20 (68)	...	Resistant	...	253
405	S40500	...	Molten	...	550 (1022)	...	Poor	...	253
409	S40900	...	...	25	20 (68)	...	Resistant	...	253
409	S40900	...	...	50	20 (68)	...	Resistant	...	253
409	S40900	...	Molten	...	550 (1022)	...	Poor	...	253
410	S41000	...	...	25	20 (68)	...	Resistant	...	253
410	S41000	...	...	50	20 (68)	...	Resistant	...	253
410	S41000	...	Molten	...	550 (1022)	...	Poor	...	253
416	S41600	...	...	25	20 (68)	...	Resistant	...	253
416	S41600	...	...	50	20 (68)	...	Resistant	...	253
416	S41600	...	Molten	...	550 (1022)	...	Poor	...	253
420	S42000	...	...	25	20 (68)	...	Resistant	...	253
420	S42000	...	...	50	20 (68)	...	Resistant	...	253
420	S42000	...	Molten	...	550 (1022)	...	Poor	...	253
430	S43000	...	...	25	20 (68)	...	Resistant	...	253
430	S43000	...	...	25	Boiling	...	Resistant	...	253
430	S43000	...	...	50	20 (68)	...	Resistant	...	253
430	S43000	...	...	50	Boiling	...	Resistant	...	253
430	S43000	...	Molten	...	550 (1022)	...	Resistant	...	253
434	S43400	...	...	25	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	25	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Resistant	...	253
434	S43400	...	Molten	...	550 (1022)	...	Resistant	...	253
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253
F51	S31803	...	...	25	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253
F51	S31803	...	Molten	...	550 (1022)	...	Resistant	...	253

Potassium Oxalate

Potassium oxalate, $K_2C_2O_4 \cdot H_2O$, is odorless, efflorescent, water-soluble, colorless crystals that decompose when heated. Used in analytical chemistry and photography, and as a bleach and oxalic acid source.

Corrosion Behavior of Various Metals and Alloys in Potassium Oxalate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Oxalate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Potassium Permanganate

Also known as purple salt, KMnO4 is highly oxidative, water-soluble, purple crystals with a sweet taste that decompose at 240 °C and explode in contact with oxidizable materials. Used as a disinfectant and analytical reagent, in dyes, bleaches, and medicines, and as a chemical intermediate.

Corrosion Behavior of Various Metals and Alloys in Potassium Permanganate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
301	S30100	...	...	All concentrations	Boiling	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	Boiling	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	Boiling	...	Good	...	253
303	S30300	...	...	All concentrations	Boiling	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	Boiling	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	Boiling	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Permanganate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	Boiling	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	Boiling	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	Boiling	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	Boiling	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	Boiling	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	Boiling	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	Boiling	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	Boiling	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	Boiling	...	Resistant	...	253
403	S40300	...	...	All concentrations	20 (68)	...	Resistant	...	253
403	S40300	...	...	All concentrations	Boiling	...	Poor	...	253
405	S40500	...	...	All concentrations	20 (68)	...	Resistant	...	253
405	S40500	...	...	All concentrations	Boiling	...	Poor	...	253
409	S40900	...	...	All concentrations	20 (68)	...	Resistant	...	253
409	S40900	...	...	All concentrations	Boiling	...	Poor	...	253
410	S41000	...	...	All concentrations	20 (68)	...	Resistant	...	253
410	S41000	...	...	All concentrations	Boiling	...	Poor	...	253
416	S41600	...	...	All concentrations	20 (68)	...	Resistant	...	253
416	S41600	...	...	All concentrations	Boiling	...	Poor	...	253
420	S42000	...	...	All concentrations	20 (68)	...	Resistant	...	253
420	S42000	...	...	All concentrations	Boiling	...	Poor	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	Boiling	...	Good	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	Boiling	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	Boiling	...	Resistant	...	253

Potassium Sulfate

Potassium sulfate, K_2SO_4, also known as salt of Lemery and arcanite, is a colorless crystalline solid that melts at 1072 °C (1960 °F). It is soluble in water, but insoluble in alcohol. Potassium sulfate is used in manufacturing glass, aluminum, fertilizers, and in medicine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. During testing at ambient temperature and 100% relative humidity, aluminum alloys 3003 and 5154 resisted attack by solid potassium sulfate. When the temperature was increased to 54 °C (130 °F), these alloys endured mild attack (0.075 mm/yr, or 3 mils/yr).

Corrosion Behavior of Various Metals and Alloys in Potassium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	...	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Provided reducing agents are not present	...	Melting point	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	10	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Potassium Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Potassium Thiocyanate

Potassium thiocyanate, KSCN, also known as potassium sulfocyanate and potassium rhodanide, is a colorless deliquescent crystalline solid that melts at 173 °C (343 °F) and decomposes at 500 °C (932 °F). Soluble in water and alcohol, it has no odor and a saline taste. Potassium thiocyanate is used in printing and dyeing textiles, freezing mixtures, manufacturing chemicals, photography and medicine.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Laboratory testing under conditions of 100% relative humidity and ambient temperature showed aluminum alloy 3003 to be resistant to solid potassium thiocyanate and aqueous solutions (including saturated) of potassium thiocyanate.

Corrosion Behavior of Various Metals and Alloys in Potassium Thiocyanate

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20-100 (68-212)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20-100 (68-212)	...	Resistant	...	92

Printing Ink

A viscous to semisolid suspension of finely divided pigment in a drying oil such as heat-bodied linseed oil. Alkyd, phenol-formaldehyde, or other synthetic resins are frequently used as binder, and cobalt, manganese, and lead soaps are added to catalyze the oxidative drying reaction. Some types of inks dry by evaporation of a volatile solvent rather than by oxidation and polymerization of a drying oil or resin. Use distribution is: offset 40%, gravure 23%, flexographic 18%, letterpress 9%, screen 4%, other 6%.

Corrosion Behavior of Various Metals and Alloys in Printing Ink

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Good	...	253
405	S40500	...	...	...	20 (68)	...	Good	...	253
409	S40900	...	...	...	20 (68)	...	Good	...	253
410	S41000	...	...	...	20 (68)	...	Good	...	253
416	S41600	...	...	...	20 (68)	...	Good	...	253
420	S42000	...	...	...	20 (68)	...	Good	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Propionic Acid

Propionic acid, CH_3CH_2COOH, also known as propanoic acid and methylacetic acid, is a clear, colorless liquid that boils at 140 °C (284 °F). It has a pungent odor and is soluble in water and alcohol. Propionic acid is used in nickel electroplating solutions, perfumes, artificial flavors, pharmaceuticals, and manufacturing propionates.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for

corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Alloy Steels. Alloy steel is attacked rapidly by propionic acid.

Stainless Steels. Type 304 stainless steel resists attack by propionic acid at room temperature and by its aqueous solutions with concentrations that are less than 50% at the boiling point. At the boiling temperature with concentrations ranging between 80 and 100%, type 304 stainless steel exhibits borderline passivity to propionic acid, and its use should be avoided. Type 316 stainless steel is recommended for use with hot concentrated solutions of propionic acid. Corrosion tests in the exact environment should be run to determine if intergranular attack is a problem before the use of a low-carbon grade (type 316L). Impurities strongly affect the corrosion rate.

Aluminum. Aluminum alloy 1100 resisted attack by aqueous solutions of propionic acid (0.5 to 100%) in tests at ambient temperature. However, propionic acid solutions became corrosive at higher temperatures and anhydrous propionic acid was very corrosive. Aluminum alloy tanks and drums have been used to ship, store, and handle propionic acid.

Copper. Copper has acceptable rates of corrosion in all concentrations of propionic acid in the absence of air.

Nickel. Incoloy alloy 800 has good resistance to propionic acid and is suitable for service, except in the most severe corrosive conditions.

Corrosion Behavior of Various Metals and Alloys in Propionic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	...	All	Boiling	...	0.05 (2) max	...	8
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	4
Nickel and alloys									
Alloy 400	N04400	...	No attempt made to control aeration	50	50 (120)	...	0.28 (11.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	50	75 (165)	...	0.13 (5.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	50	Boiling	...	0.076 (3.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	80	50 (120)	...	0.4 (16.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	80	75 (165)	...	0.15 (6.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	80	Boiling	...	0.25 (10.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	99	50 (120)	...	0.48 (19.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	99	75 (165)	...	1.19 (47.0)	...	101
Alloy 400	N04400	...	No attempt made to control aeration	99	Boiling	...	0.53 (21.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	50	50 (120)	...	0.38 (15.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	50	75 (165)	...	0.1 (4.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	50	Boiling	...	0.05 (2.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	80	50 (120)	...	0.61 (24.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	80	75 (165)	...	0.3 (12.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	80	Boiling	...	0.13 (5.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	99	50 (120)	...	0.15 (6.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	99	75 (165)	...	0.64 (25.0)	...	101
Nickel alloy B	N10001	...	No attempt made to control aeration	99	Boiling	...	0.28 (11.0)	...	101
Nickel alloy C	...	...	No attempt made to control aeration	50	50 (120)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	50	75 (165)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	50	Boiling	...	0.025 (1.0)	...	101
Nickel alloy C	...	...	No attempt made to control aeration	80	50 (120)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	80	75 (165)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	80	Boiling	...	0.025 (1.0)	...	101
Nickel alloy C	...	...	No attempt made to control aeration	99	50 (120)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	99	75 (165)	...	Resistant	...	101
Nickel alloy C	...	...	No attempt made to control aeration	99	Boiling	...	0.025 (1.0)	...	101
Refractory metals and alloys									
Titanium	...	...	...	Vapor	190 (374)	...	Poor	...	90

(Continued)

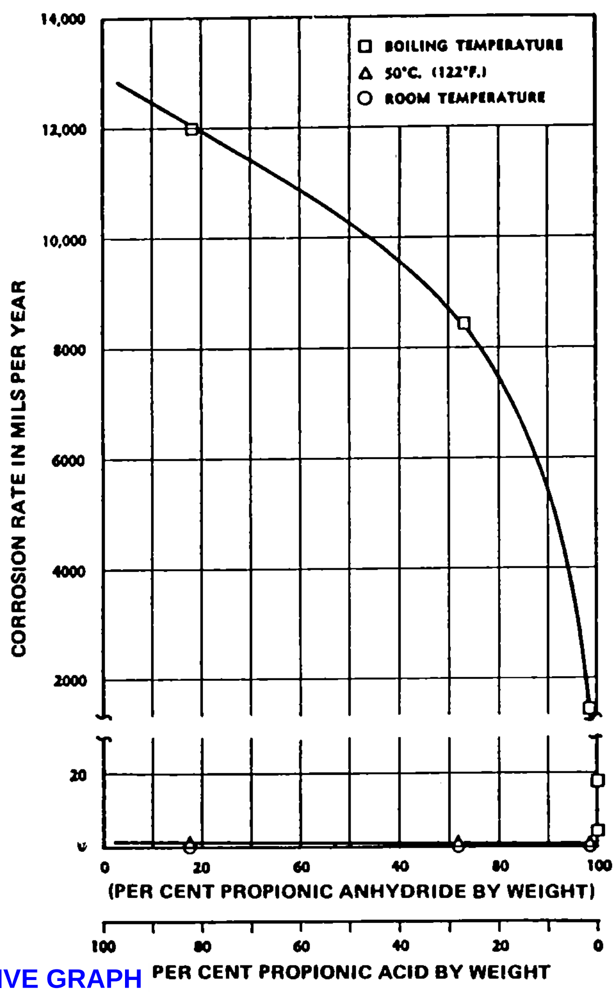
Corrosion Behavior of Various Metals and Alloys in Propionic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 45% butyric acid, 5% heavy esters during 155 d, 96% acetic acid, 2% nonvolatiles, 1% propionic acid, 1% water during 38 d	50	121 (251)	193 d	0.05 (2)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 16.5% glycol esters, 12% butyric acid, 1.5% acetic acid	70	156 (314)	566 d	0.43 (17)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 5% sulfuric acid, 0.5% butyric acid, 0.5% decomposition products	94	150 (302)	12 d	0.02 (0.7)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 12% butyric acid, 5% sulfuric acid	83	138 (280)	10 d	1.1 (45)	...	89
304	S30400	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 1% sulfuric acid	99	138 (280)	10 d	0.5 (20)	...	89
304	S30400	...	Chemical processing; no aeration; rapid agitation. Plus 10-12% butyric acid, 4-7% acetic acid, remainder unknown	60-65	155 (311)	466 d	0.68 (27)	Severe pitting	89
304	S30400	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	145 (293)	200 d	1.0 (38)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 45% butyric acid, 5% heavy esters during 155 d, 96% acetic acid, 2% nonvolatiles, 1% propionic acid, 1% water during 38 d	50	121 (251)	193 d	0.02 (0.7)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 16.5% glycol esters, 12% butyric acid, 1.5% acetic acid	70	156 (314)	566 d	0.12 (4.6)	Slight pitting	89
316	S31600	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 5% sulfuric acid, 0.5% butyric acid, 0.5% decomposition products	94	150 (302)	12 d	0.01 (0.3)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 12% butyric acid, 5% sulfuric acid	83	138 (280)	10 d	0.08 (3)	...	89
316	S31600	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 1% sulfuric acid	99	138 (280)	10 d	0.11 (4.3)	...	89
316	S31600	...	Chemical processing; no aeration; rapid agitation. Plus 10-12% butyric acid, 4-7% acetic acid, remainder unknown	60-65	155 (311)	466 d	0.15 (6.1)	Moderate pitting	89
316	S31600	...	Rayon processing; field or pilot plant test; no aeration; rapid agitation	100	145 (293)	200 d	0.3 (12)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Plus 45% butyric acid, 5% heavy esters during 155 d, 96% acetic acid, 2% nonvolatiles, 1% propionic acid, 1% water during 38 d	50	121 (251)	193 d	0.1 (0.4)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 16.5% glycol esters, 12% butyric acid, 1.5% acetic acid	70	156 (314)	566 d	0.08 (3)	...	89

(Continued)

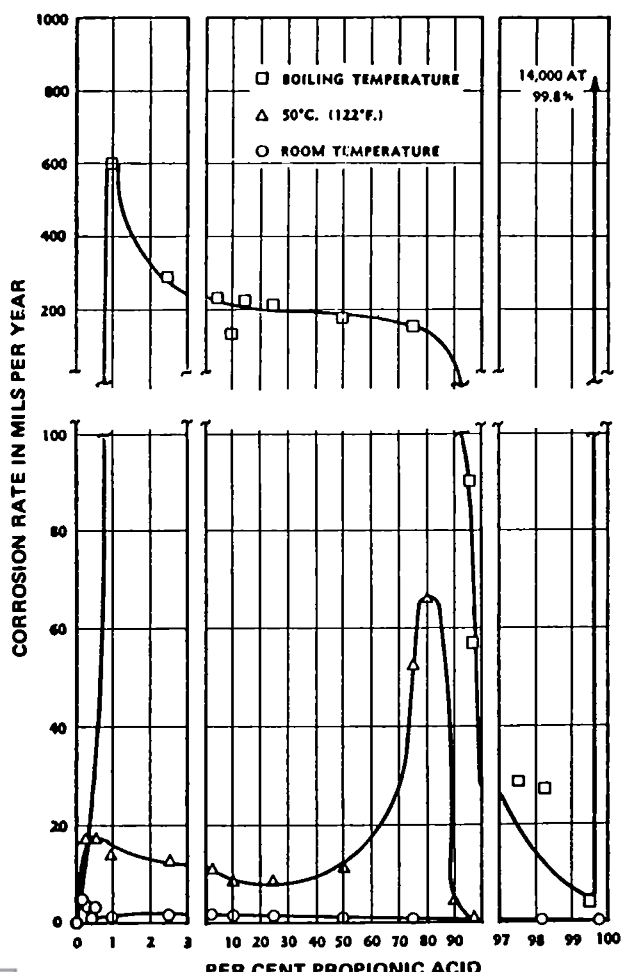
Corrosion Behavior of Various Metals and Alloys in Propionic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Chemical processing; field or pilot plant test; no aeration; slight to moderate agitation. Plus 5% sulfuric acid, 0.5% butyric acid, 0.5% decomposition products.	94	150 (302)	12 d	0.01 (0.2)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderater agitation. Plus 12% butyric acid, 5% sulfuric acid	83	138 (280)	10 d	0.09 (3.5)	...	89
317	S31700	...	Chemical processing; field or pilot plant test; slight to moderate aeration; slight to moderate agitation. Plus 1% sulfuric acid	99	138 (280)	10 d	0.01 (5)	...	89
317	S31700	...	Chemical processing; no aeration; rapid agitation. Plus 10-12% butyric acid, 4-7% acetic acid, remainder unknown	60-655	155 (311)	466 d	0.10 (3.9)	...	89



LIVE GRAPH
Click here to view

Aluminum. Effect of concentration and temperature on the resistance of alloy 1100 in propionic acid/propionic anhydride solutions. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 50.



LIVE GRAPH
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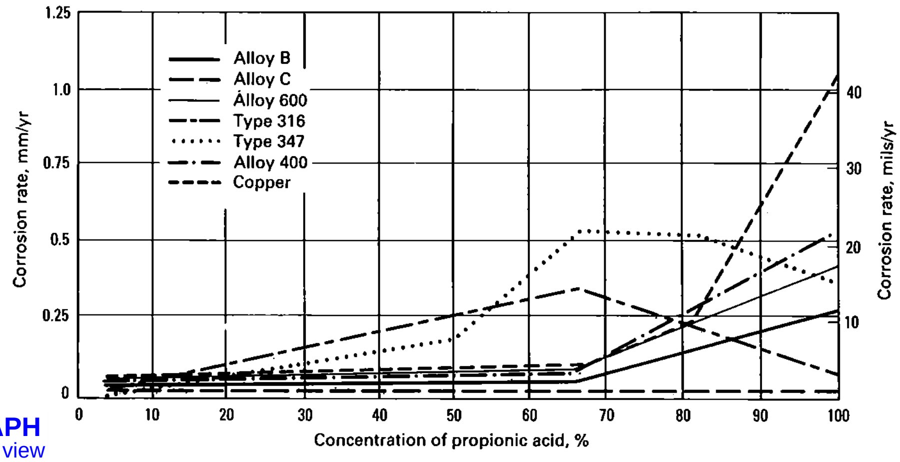
Aluminum. Effect of concentration and temperature on the resistance of alloy 1100 in propionic acid. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 50.



LIVE GRAPH
Click here to view

Various alloys. Corrosion of various alloys in boiling propionic acid. Source: G.B. Elder, in *Process Industries Corrosion*, National Association of Corrosion Engineers, Houston, 1975, 247.

Pyridine

Pyridine, C_5H_5N, is a yellowish, flammable, poisonous organic solvent with a very distinctive and penetrating odor. Pyridine is soluble in water, alcohol, benzene, and ether. It has a boiling point of 116 °C (240 °F). Pyridine is used in paints, medicine, and textile dyeing.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests at ambient temperature, aluminum alloys 1100 and 3003 resisted pyridine. Aluminum alloy 3003 experienced mild attack (0.075 mm/yr, or 5 mils/yr) in aqueous solutions of pyridine with concentrations of 1 and 5%. Aluminum alloy condensers and dephlegmators have serviced pyridine.

Corrosion Behavior of Various Metals and Alloys in Pyridine

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	...	...	...	All	Boiling	...	0.05 (2) max	...	7
Gold	...	...	...	All	Boiling	...	0.05 (2) max	...	8
Magnesium	...	...	Acid free	100	Room	...	0.05 (2) max	...	119
Platinum	...	...	...	All	Boiling	...	Suitable	...	6

Pyrogallic Acid

Also known as pyrogallol and 1,2,3-trihydroxy-benzene, $C_6H_3(OH)_3$ is white, lustrous crystals that turn gray on exposure to light. It is soluble in water, alcohol, and ether. A solution of pyrogallol acquires a brown color on exposure to air. This absorption of oxygen and change of color take place rapidly when the solution is made alkaline. Derivation is by heating gallic acid in an autoclave with three times its weight of water.

Uses are as a protective colloid in preparation of metallic colloidal solutions, photography, dyes, intermediates, synthetic drugs, medicine (antibacterial), process engraving, laboratory reagent, gas analysis (an oxygen absorber), reducing agent, and antioxidant in lubricating oils.

Corrosion Behavior of Various Metals and Alloys in Pyrogallic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253

Quinine Sulfate

Basic quinine sulfate is $C_{40}H_{50}N_4O_8S$; the dihyrate, $C_{40}H_{50}N_4O_8S{\cdot}2H_2O$, is dull needles or rods making a light and readily compressible mass that becomes brownish on exposure to light. Slightly soluble in chloroform and ether. Should be kept well closed and protected from light.

Corrosion Behavior of Various Metals and Alloys in Quinine Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	20	0 (32)	...	Resistant	...	253
302	S30200	...	...	20	0 (32)	...	Resistant	...	253
303	S30300	...	...	20	0 (32)	...	Resistant	...	253
303	S30300	...	...	20	0 (32)	...	Resistant	...	253
304	S30400	...	...	20	0 (32)	...	Resistant	...	253
304L	S30403	...	...	20	0 (32)	...	Resistant	...	253
304LN	S30453	...	...	20	0 (32)	...	Resistant	...	253
316	S31600	...	...	20	0 (32)	...	Resistant	...	253
316F	S31620	...	...	20	0 (32)	...	Resistant	...	253
316L	S31603	...	...	20	0 (32)	...	Resistant	...	253

(Continued)

Uses are as a protective colloid in preparation of metallic colloidal solutions, photography, dyes, intermediates, synthetic drugs, medicine (antibacterial), process engraving, laboratory reagent, gas analysis (an oxygen absorber), reducing agent, and antioxidant in lubricating oils.

Corrosion Behavior of Various Metals and Alloys in Pyrogallic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	All concentrations	20 (68)	...	Resistant	...	253
302	S30200	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
303	S30300	...	...	All concentrations	20 (68)	...	Resistant	...	253
304	S30400	...	...	All concentrations	20 (68)	...	Resistant	...	253
304L	S30403	...	...	All concentrations	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All concentrations	20 (68)	...	Resistant	...	253
316	S31600	...	...	All concentrations	20 (68)	...	Resistant	...	253
316F	S31620	...	...	All concentrations	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All concentrations	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All concentrations	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All concentrations	20 (68)	...	Resistant	...	253
317L	S31703	...	...	All concentrations	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All concentrations	20 (68)	...	Resistant	...	253
321	S32100	...	...	All concentrations	20 (68)	...	Resistant	...	253
329	S32900	...	...	All concentrations	20 (68)	...	Resistant	...	253
347	S34700	...	...	All concentrations	20 (68)	...	Resistant	...	253
430	S43000	...	...	All concentrations	20 (68)	...	Resistant	...	253
434	S43400	...	...	All concentrations	20 (68)	...	Resistant	...	253
F51	S31803	...	...	All concentrations	20 (68)	...	Resistant	...	253

Quinine Sulfate

Basic quinine sulfate is $C_{40}H_{50}N_4O_8S$; the dihyrate, $C_{40}H_{50}N_4O_8S{\cdot}2H_2O$, is dull needles or rods making a light and readily compressible mass that becomes brownish on exposure to light. Slightly soluble in chloroform and ether. Should be kept well closed and protected from light.

Corrosion Behavior of Various Metals and Alloys in Quinine Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	20	0 (32)	...	Resistant	...	253
302	S30200	...	...	20	0 (32)	...	Resistant	...	253
303	S30300	...	...	20	0 (32)	...	Resistant	...	253
303	S30300	...	...	20	0 (32)	...	Resistant	...	253
304	S30400	...	...	20	0 (32)	...	Resistant	...	253
304L	S30403	...	...	20	0 (32)	...	Resistant	...	253
304LN	S30453	...	...	20	0 (32)	...	Resistant	...	253
316	S31600	...	...	20	0 (32)	...	Resistant	...	253
316F	S31620	...	...	20	0 (32)	...	Resistant	...	253
316L	S31603	...	...	20	0 (32)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Quinine Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	20	0 (32)	...	Resistant	...	253
316Ti	S31635	...	...	20	0 (32)	...	Resistant	...	253
317L	S31703	...	...	20	0 (32)	...	Resistant	...	253
317LN	S31725	...	...	20	0 (32)	...	Resistant	...	253
321	S32100	...	...	20	0 (32)	...	Resistant	...	253
329	S32900	...	...	20	0 (32)	...	Resistant	...	253
347	S34700	...	...	20	0 (32)	...	Resistant	...	253
403	S40300	...	...	20	0 (32)	...	Resistant	...	253
405	S40500	...	...	20	0 (32)	...	Resistant	...	253
409	S40900	...	...	20	0 (32)	...	Resistant	...	253
410	S41000	...	...	20	0 (32)	...	Resistant	...	253
416	S41600	...	...	20	0 (32)	...	Resistant	...	253
420	S42000	...	...	20	0 (32)	...	Resistant	...	253
430	S43000	...	...	20	0 (32)	...	Resistant	...	253
434	S43400	...	...	20	0 (32)	...	Resistant	...	253
F51	S31803	...	...	20	0 (32)	...	Resistant	...	253

Salicylic Acid

Also known as o-hydroxybenzoic acid, $C_6H_4(OH)(COOH)$ is a white powder with an acrid taste that is stable in air but gradually discolored by light. Soluble in acetone, oil of turpentine, alcohol, ether, benzene; slightly soluble in water; and combustible. Derived by reacting a hot solution of sodium phenolate with carbon dioxide and acidifying the sodium salt thus formed. Used in the manufacture of aspirin and salicylates, resins, dyestuff intermediate, prevulcanization inhibitor, analytical reagent, and fungicide.

Corrosion Behavior of Various Metals and Alloys in Salicylic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Corrosion Behavior of Various Metals and Alloys in Quinine Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	20	0 (32)	...	Resistant	...	253
316Ti	S31635	...	...	20	0 (32)	...	Resistant	...	253
317L	S31703	...	...	20	0 (32)	...	Resistant	...	253
317LN	S31725	...	...	20	0 (32)	...	Resistant	...	253
321	S32100	...	...	20	0 (32)	...	Resistant	...	253
329	S32900	...	...	20	0 (32)	...	Resistant	...	253
347	S34700	...	...	20	0 (32)	...	Resistant	...	253
403	S40300	...	...	20	0 (32)	...	Resistant	...	253
405	S40500	...	...	20	0 (32)	...	Resistant	...	253
409	S40900	...	...	20	0 (32)	...	Resistant	...	253
410	S41000	...	...	20	0 (32)	...	Resistant	...	253
416	S41600	...	...	20	0 (32)	...	Resistant	...	253
420	S42000	...	...	20	0 (32)	...	Resistant	...	253
430	S43000	...	...	20	0 (32)	...	Resistant	...	253
434	S43400	...	...	20	0 (32)	...	Resistant	...	253
F51	S31803	...	...	20	0 (32)	...	Resistant	...	253

Salicylic Acid

Also known as o-hydroxybenzoic acid, $C_6H_4(OH)(COOH)$ is a white powder with an acrid taste that is stable in air but gradually discolored by light. Soluble in acetone, oil of turpentine, alcohol, ether, benzene; slightly soluble in water; and combustible. Derived by reacting a hot solution of sodium phenolate with carbon dioxide and acidifying the sodium salt thus formed. Used in the manufacture of aspirin and salicylates, resins, dyestuff intermediate, prevulcanization inhibitor, analytical reagent, and fungicide.

Corrosion Behavior of Various Metals and Alloys in Salicylic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Seawater

Seawater is a biologically active medium that contains a large number of microscopic and macroscopic organisms. Many of these organisms are commonly observed in association with solid surfaces in seawater, where they form biofouling films. Immersion of any solid surface in seawater initiates a continuous and dynamic process, beginning with adsorption of nonliving, dissolved organic material and continuing through the formation of bacterial and algal slime films and the settlement and growth of various macroscopic plants and animals. This process, by which the surfaces of all structural materials immersed in seawater become colonized, adds to the variability of the ocean environment in which corrosion occurs.

Bacterial Films. The process of colonization begins immediately upon immersion with the adsorption of a nonliving organic conditioning film. This conditioning film is nearly complete within the first 2 h of immersion, at which time the initial colonizing bacteria begin to attach in substantial numbers. The bacterial slime film develops over a period of 24 to 48 h in most natural seawaters, although further changes in the film can often be observed over more than a 2-week period.

The bacterial film changes the chemistry at the metal/liquid interface in various ways. As the biofilm grows, the bacteria in the film produce a number of organic by-products, including organic acids, hydrogen sulfide, and protein-rich polymeric materials commonly known as slime. The first effect of the composite film of bacteria and slime is to create a diffusion barrier between the liquid/metal interface and the bulk seawater. The barrier itself is over 90% water, so it does not in fact isolate the interface—instead it supports strong concentration gradients for various chemical species. As such, the water chemistry at the interface may be different from that in the bulk water, although the two are closely coupled through diffusive processes.

Oxygen and hydrogen, the two chemical species often implicated in corrosion, are also important in the metabolism of bacteria. A given bacterial slime film can be either a source or a sink for either oxygen or hydrogen. Moreover, these films are rarely continuous. Usually, they provide only spotty coverage of the metal surface. Thus, they are capable of inducing oxygen or other chemical concentration cells. Bacterial action on decaying matter in the slime film can also result in the production of ammonia and sulfides. Ammonia causes stress-corrosion cracking of copper alloys, and sulfides have been implicated in accelerated localized and/or uniform corrosion of copper alloys and steels.

Under anaerobic conditions, such as those found in marshy coastal areas, in which all the dissolved oxygen in the mud is used in the decay of organic matter, the corrosion rate of steel is expected to be very low. Under these conditions, however, the sulfate-reducing bacteria ***desulfovibrio*** use the hydrogen produced at the metal surface in reducing sulfates from the decaying material to sulfides, including hydrogen sulfide. The sulfides combine with iron from the steel to produce iron sulfide film, which is itself corrosive. The bacteria thus transform a benign environment into an aggressive one in which steel corrodes quite rapidly.

Even under open ocean conditions at air saturation, the presence of a bacterial slime film can result in anaerobic conditions at the metal surface. Oxygen-utilizing bacteria in the initial film may eventually increase sufficiently in number so that they use all of the oxygen diffusing through the film before it can reach the metal surface. This creates an anaerobic layer right next to the metal surface and provides a place where the sulfate-reducing organisms can flourish. The biofilm is able to change the chemistry of the electrolyte substantially at the water/metal interface. Thus, the corrosion rate may depend as much on the electrolyte as it does on the ambient bulk seawater chemistry.

Macrofouling Films. Within the first 2 to 3 days following immersion, the solid surface, already having acquired both conditioning and bacterial films, begins to be colonized by the macrofouling organisms. A heavy encrustation of these organisms can have detrimental effects on marine structures. In terms of corrosion, the effects of the macrofouling layer are similar to the microfouling mechanism. If the macrofoulers form a continuous layer, they decrease the availability of dissolved oxygen at the liquid/metal interface and can reduce the rate of corrosion. If the layer is discontinuous, they may induce oxygen or chemical concentration cells, thus leading to various types of localized corrosion.

Seawater Chemistry. Oceans cover over 70% of the earth's surface, with an average depth of about 2 miles. The average salt content of the sea is 3.5%, with the composition comprised of the following percentages: 77.76% NaCl, 10.88% $MgCl_2$, 4.74% $MgSO_4$, 3.60% $CaSO_4$, 2.46% K_2SO_4, 0.22% $MgBr_2$, and 0.34% $CaCO_3$. In addition, seawater contains measurable quantities of iodine, fluorine, arsenic, gold, silver, rubidium, copper, barium, phosphorus, manganese, lithium, lead, iron, strontium, and zinc. Ammonia is also present, with free oxygen, nitrogen, and other gases. In some seawater compositions, hydrogen sulfide is also present. Mineral and organic materials are also carried in suspension by the seawater, particularly near the mouths of rivers (Ref 1).

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Service experience with 1*xxx*, 3*xxx*, and 6*xxx* wrought aluminum alloys in marine applications, including structures, pipeline, boats, and ships, demonstrates their good resistance and long life under conditions of partial, intermittent, or total immersion. Casting alloys of the 356.0 and 514.0 types also show high resistance to seawater corrosion, and these alloys are used widely for fittings, housings, and other marine parts.

Among the wrought alloys, those of the 5*xxx* series are the most resistant and the most widely used because of their favorable strength and good weldability. Alloys of the 3*xxx* series are also highly resistant and are suitable where their strength range is adequate. With the 3*xxx* and 5*xxx* series alloys, thinning by uniform corrosion is negligible, and the rate of corrosion based on weight loss does not exceed about 5 μm/yr (0.2 mil/yr), which is generally less than 5% of the rate for unprotected low-

carbon steel in seawater. Corrosion is mainly of the pitting or crevice type, characterized by deceleration of penetration with time from rates of 3 to 6 μm/yr (0.1 to 0.2 mil/yr) in the first year to average rates over a 10-year period of 0.8 to 1.5 μm/yr (0.03 to 0.06 mil/yr).

The aluminum-magnesium-silicon alloys are somewhat less resistant; although no general thinning occurs, weight loss may be two to three times that for 5*xxx* alloys. The more severe corrosion is reflected in larger and more numerous pits. Alloys of the 2*xxx* and 7*xxx* series, which contain copper, are considerably less resistant to seawater than 3*xxx*, 5*xxx*, and 6*xxx* alloys and are generally not used unprotected.

In a 10-year test of tidal and full-immersion exposure of seven 5*xxx* alloys and super-purity aluminum 1199, it was found that full immersion generally resulted in more extensive corrosion than tidal exposure, although the reverse relationship has also been observed. Tensile strength losses were 5% or less, and yield strength losses were less than 5% in the panels that were completely immersed. Losses were generally lower in those exposed to tidal immersion.

In a study of the corrosion resistance of aluminum alloy plate, with and without riveted or welded joints, in flowing seawater, all assemblies and panels underwent only moderate pitting and retained most of their original strength.

The corrosion behavior of aluminum alloys in deep seawater, as indicated from tests at a depth of 1.6 km (1 mile), is generally the same as at the surface, except that the rate of pit penetration may be higher and the effect of crevices somewhat greater. The corrosivity of unpolluted, full-strength seawater depends on several factors—dissolved oxygen content, pH, temperature, velocity of the water flow, and the presence or absence of heavy-metal ions, particularly copper. The corrosion rate tends to be increased by decreasing temperature, pH, and flow velocity and by increasing dissolved oxygen. The higher corrosion rate in deep water is not caused by low dissolved oxygen, but is caused by the combination of low pH and low temperature.

Surface water conditions at various tropical locations are benign to aluminum alloys because of their high temperature, high pH, and high oxygen concentrations and the virtual absence of heavy-metal contamination. A variety of aluminum alloys in the form of heat exchanger tubing have been tested for up to 3 years in surface water off Keahole Point, Hawaii, with no significant pitting or crevice corrosion.

Experience with seawater desalination units has demonstrated the high degree of resistance of aluminum alloys to deaerated seawater at temperatures up to 120 °C (250 °F). For example, a 11,355-L/day (3000-gal/day) multiflash aluminum unit at the Office of Saline Water Materials Test Center at Freeport, Texas, operated at 99% efficiency and with minimal corrosion for more than 3 years under process conditions selected to match those of a commercial installation. Such experience has shown, however, that galvanic attack of aluminum alloys in contact with dissimilar metals is more severe at elevated temperatures than at room temperature.

Cast Irons. Seawater presents some special problems for cast irons. Gray iron may experience graphitic corrosion in calm seawater. It will also be galvanically active in contact with most stainless steels, copper-nickel alloys, titanium, and Hastelloy C. Because these materials are frequently used in seawater structures, this potential for galvanic corrosion must be considered. In calm seawater, the corrosion resistance of cast iron is not greatly affected by the presence of crevices. However, intermittent exposure to seawater is very corrosive to unalloyed cast irons. Use of high-alloy cast irons in water is relatively limited. High-nickel austenitic cast irons are used to increase the resistance of cast iron components to pitting in calm seawater. High-silicon cast iron is used to produce anodes for the cathodic protection systems used in seawater and brackish water.

Carbon Steels. Corrosion of steel in seawater is a function of water salinity, temperature, oxygen content, velocity, resistivity, and chemistry. The fatigue life of steel exposed to seawater is shorter than that of steel exposed to air because of corrosion fatigue. Steel immersed in seawater does not exhibit an endurance limit. Because there is no endurance limit, unprotected steel exposed to seawater is susceptible to fatigue failure even at low stress levels after long-term cyclic service. The corrosion fatigue effects are eliminated by the application of cathodic protection.

The corrosion of steels in aerated seawater is about the same overall as in aerated freshwater, but this is somewhat misleading because the improved electrical conductivity of seawater can lead to increased pitting. Furthermore, because of the improved conductance, the concentration cells can operate over long distances, and this leads to a more nonuniform attack than in freshwater. It is also well documented that alternate cycling of immersion and exposure to air produces more pitting attack than continuous immersion.

A study was done in England on the effects of various alloying additions and exposure conditions on the corrosion behavior of steel bars exposed to seawater for a period of 15 years. Although this study showed a beneficial effect of both copper and nickel additions, other studies reported no significant benefit. Interestingly, the corrosion rates of specimens completely immersed in seawater do not appear to depend on the geographical location of the test site; therefore, by inference, the mean temperature does not appear to play an important role.

This constancy of the corrosion rate in seawater has been attributed to the more rapid fouling of the exposed steel by marine organisms, such as barnacles and algae, in warmer seas. It is further speculated that this fouling offsets the increases expected from the temperature rise. For example, it has been demonstrated that, under laboratory conditions of rapidly flowing seawater where fouling is suppressed, a rise of 18 °C (32 °F) will approximately double the attack rate. In actual marine exposures, periods of rapid flow from tidal motion may not be effective, because the slack periods at reversal may allow marine organisms to attach themselves to the metal surface. If these organisms can survive the subsequent high flow, then a growth on the exposed surface can develop. This effectively reduces the velocity of seawater at the metal/water interface so that bulk flow rates are no longer rate determining.

Stainless Steels. For service in seawater, stainless steels must be chosen to resist chloride pitting. The amount of chloride that can be tolerated is expected to be higher with higher pH and cleaner stainless steel surfaces, that is, the absence of deposits. For example, type 304 stainless steel may resist pitting in chloride levels of 1000 ppm or higher in the absence of fouling, crevices, or stagnant conditions. The presence of one or more of these conditions can allow chlorides to concentrate at the metal surface and initiate pits. Several high-performance stainless steels have been used to resist chloride pitting in brackish water or seawater. High-performance austenitic grades have been useful in feedwater heaters, although duplex stainless steels may also be considered because of their high strength. Ferritic stainless steels have proved to be economically competitive in exchangers and condensers. High-performance austenitic and ferritic grades have been satisfactory for seawater-cooled units. These grades include MONIT, Al-29-4C, Usinor 290Mo, Sea-Cure, AL-6X, AL-6XN, and 254SMO stainless steels.

Stainless steels are more likely to be attacked in low-velocity seawater or at crevices resulting from equipment design or attachment of barnacles. Type 304 and 316 stainless steels suffer deep pitting if the seawater flow rate decreases below about 1.5 m/s (5 ft/s) because of the crevices produced by fouling organisms. However, in one study, type 316 stainless steel provided satisfactory service as tubing in the heat recovery section of a desalination test plant with relatively high flow rates. Type 304 and 316 are frequently used for seawater heat exchange tubing when the flow rate is kept above about 10 ft/s.

The choice of stainless steel for seawater service can depend on whether stagnant conditions can be minimized or eliminated. For example, boat shafting of 17Cr-4Ni stainless steel has been used for trawlers where stagnant exposure and the associated pitting would not be expected to be a problem. When seagoing vessels are expected to be idle for extended periods, more resistant boat shaft materials, such as 22Cr-13Ni-5Mn stainless steel, are considered. Boat shafts with intermediate corrosion resistance are provided by 18Cr-2Ni-12Mn and high-nitrogen type 304 (type 304HN) stainless steel.

The possibility of galvanic corrosion must be considered if stainless steel is to be used in contact with other metals in seawater. Preferably, only those materials that exhibit closely related electrode potentials should be coupled to avoid attack of the less noble material. Galvanic differences have been used to advantage in the cathodic protection of stainless steel in seawater. Crevice corrosion and pitting of austenitic type 302 and 316 stainless steels have been prevented by cathodic protection, but type 410 and 430 stainless steels develop hydrogen blisters at current densities below those required for complete protection. Other factors that should be noted when applying stainless steels in seawater include the effects of high velocity, aeration, and temperature. Stainless steels generally show excellent resistance to high velocities, impingement attack, and cavitation in seawater. Also, stainless steels provide optimum service in aerated seawater because a lack of aeration at a specific site often leads to crevice attack. Very little oxygen is required to maintain the passive film on a clean stainless surface. Increasing the temperature from ambient to about 50 °C (120 °F) often reduces attack of stainless steels, possibly because of differences in the amount of dissolved oxygen, changes in the surface film, or changes in the resistance of the exposed sample area. Further temperature increases can result in increased corrosion, such as stress-corrosion cracking.

Cemented Carbides. A study was performed on the crevice corrosion resistance of cemented carbides in seawater with specimens of type 316 stainless steel, Teflon, and silicon carbide adjacent to the cemented carbide specimens. Of the five compositions tested, only the WC-6Co specimens showed any significant attack after 1 year. The attack was moderate and progressed the least against silicon carbide and the most against the stainless steel.

Copper. An important use of copper alloys is in handling seawater in ships and tidewater power stations. Copper itself, although fairly useful, is usually less resistant to general corrosion than C44300 to C44500, C61300, C68700, C70600, or C71500. The superior performance of these alloys results from the combination of insolubility in seawater, erosion resistance, and biofouling resistance. Aluminum and phosphor bronzes are generally suitable for service in seawater. The corrosion rates of copper and its alloys in relatively quiescent seawater are typically less than 50 μm/yr (2 mils/yr).

In the laboratory and in actual service conditions, copper-nickel alloys C70600, C71500, C72200, and C71640 exhibit excellent corrosion resistance in seawater. Average corrosion rates for both C70600 and C71500 have been shown to range from 2 to 12 μm/yr (0.08 to 0.5 mil/yr), and long-term evaluations have revealed corrosion rates below 2.5 μm/yr (0.1 mil/yr) for both alloys after 14 years of exposure to quiescent and low-velocity seawater. Sixteen-year tests confirmed this same low corrosion rate.

Pitting Resistance. Alloys C70600 and C71500 both display excellent resistance to pitting in seawater. The average depth of the 20 deepest pits in C71500 observed at the end of a 16-year test was less than 127 m (5 mils). Chromium-modified copper-nickel alloys, developed for resistance to high-velocity seawater, were evaluated in both low- and high-velocity conditions. The quiescent and low-velocity performances of C72200, C70600, and C71500 were compared; results showed uniform corrosion (5 to 25 μm/yr, or 0.2 to 1 mil/yr) on all three alloys. The chromium-containing alloys, however, were slightly more susceptible to localized attack in quiet seawater. Another study reported that the pitting behavior of C72200 is influenced by the presence of iron and chromium in or out of solid solution. The fraction of iron plus chromium in solution in C72200 must be kept higher than 0.7 to avoid pitting corrosion.

Velocity Effects. Recent work has demonstrated that, although the presence of 0.01 mg/L sulfide in aerated seawater can accelerate corrosion of copper-nickel alloys, the influence of seawater velocity is more significant. The corrosion resistance of copper alloys in flowing seawater depends on the growth and maintenance of a protective film of corrosion product layers. These alloys typically exhibit velocity-dependent corrosion rates. The more adherent and protective the film on a particular alloy, the higher its breakaway velocity and the greater its resistance to impingement attack or erosion-corrosion.

Some of the earliest work on copper-nickel alloys demonstrated the beneficial effects of iron additions on seawater impingement resistance. The effects of manganese level in association with iron in copper-nickel alloys have also been investigated. Additions of 2% iron and 2% manganese to a 70Cu-30Ni alloy (C71640) have been shown to be relatively beneficial, which indicates that alloys C71640 and C72200 are markedly more resistant than C70600 at velocities up to 9 m/s (30 ft/s). The chromium-modified copper-nickel alloys also provide increased resistance to impingement attack compared to copper-nickel-iron alloys. In jet impingement tests on several copper-base alloys at impingement velocities as high as 10 m/s (33 ft/s), no measurable impingement attack was observed on alloys C72200 and C71900 at 4.6 m/s (15 ft/s).

The behavior of several copper-nickel alloys, including C71640 and C72200, have been characterized under conditions simulating partial blockage of a condenser tube. In the 1-year natural seawater tests, enhanced erosion-corrosion resistance was observed for the C71640 and C72200 alloys as compared to C70600 and C71500. Some localized pitting and/or crevice corrosion associated with the nonmetallic blockage device was noted for C71640 and C72200, with no such attack occurring for the C70600 and C71500 alloys. Superior performance of the modified copper-nickel alloys C72200 and C71640 was also observed under severely erosive conditions in seawater containing entrained sand.

Galvanic Effects. In general, the copper-base alloys are galvanically compatible with one another in seawater. The copper-nickel alloys are slightly cathodic (noble) to the nickel-free copper-base alloys, but the small differences in corrosion potential generally do not lead to serious galvanic effects unless unusually adverse anodic/cathodic area ratios are involved.

Studies have demonstrated the increased attack of less noble carbon steel coupled to copper-nickel alloys, the increased attack on the copper-nickel alloys when coupled to more noble titanium, and the general compatibility of copper-nickel alloys with aluminum bronze. Coupling copper-nickel alloys to less noble materials affords protection to the copper-nickel that effectively reduces its corrosion rate, thus inhibiting the natural fouling resistance of the alloy.

In short-term galvanic couple tests between alloy C70600 and several cast copper-base and ferrous alloys, the corrosion rate of cast 70Cu-30Ni was unaffected by coupling with an equal area of C70600, but some increased corrosion of other cast copper-base was noted. Corrosion rates of cast stainless steels were reduced, with a resultant increase in the corrosion of C70600. Gray iron displayed the largest galvanic effect, whereas the corrosion rates of Ni-Resist cast irons nominally doubled. Although some caution should be exercised in using absolute values from any short-term tests, the relative degree of acceleration of corrosion from galvanic coupling was shown to be unaffected by extending some tests with Ni-Resist/C70600 couples to 1 year.

Effect of Oxygen, Depth, and Temperature. The corrosion of copper and copper-base alloys in clean seawater is cathodically controlled by oxygen reduction, with H^+ reduction being thermodynamically unfavorable. Dissolved oxygen retards corrosion by the promotion of a protective film on the copper alloy surface, but increases the rate of corrosion by depolarizing cathodic sites and oxidizing Cu^+ ions to more aggressive Cu^{2+} ions. Other factors, such as velocity, temperature, salinity, and ocean depth, affect the dissolved oxygen content of seawater, thus influencing the corrosion rate. In general, oxygen concentration decreases with increasing salinity, temperature, and depth. These factors can vary with depth in a complex manner and also may vary from location to location in the oceans of the world.

Although cathodic control by oxygen reduction suggests a strong dependence of corrosion rate on dissolved oxygen concentration, the growth of a protective oxide film on copper-nickel alloys minimizes the influence within the normally observed range of oxygen content found in seawater. Deep ocean testing indicated that the corrosion rates of copper and copper-nickel alloys do not change significantly for dissolved oxygen contents between 1 and 6 ml/L of seawater and consequently were not significantly affected by variations in depth of exposure.

Short-term laboratory tests indicated only a small increase in corrosion rate with increasing temperature up to 30 °C (85 °F). Long-term corrosion rate data from tests conducted at a coastal site near Panama agree very well with long-term data for exposures in Wrightsville Beach, North Carolina, where the seasonal temperature variation is 5 to 30 °C (40 to 85 °F). Final steady-state corrosion rates at both locations for C71500 ranged from 1 to 3 μm/yr (0.04 to 0.12 mils/yr).

Studies performed at higher temperatures relative to those in desalination plant environments show considerable disagreement in results. From 60 to 107 °C (140 to 225 °F), temperature may increase, decrease, or have no significant effect on the corrosion rates of copper-nickel alloys. Lower corrosion rates for C70600 over an intermediate temperature range were reported in seawater corrosion tests between 32 and 107 °C (90 and 225 °F) with controlled seawater chemistry; bicarbonate alkalinity, dissolved oxygen, and pH were noted as critical factors controlling corrosion. Other studies confirmed lower average corrosion rates at 40 °C (105 °F) than at lower temperatures. The variation in results reported in the literature can perhaps be explained by variations in seawater chemistry between test sites and/or control of operating conditions in desalination plants.

Effect of Chlorine. Coastal power plants that use seawater as a coolant have long used chlorine to control fouling and slime formation. The effect of chlorination, both continuous and intermittent, on the corrosion of copper-nickel alloys was studied. Continuous chlorine additions increased the corrosion rate of C70600 by a factor of two. Intermittent chlorination at a higher level controlled fouling, yet had no apparent effect on corrosion rates. A net reduction was noted in the corrosion rate of C71500 with continuous and most intermittent chlorine additions.

Seawater impingement tests were conducted on C70600, C71500, and C71640 with continuous additions of chlorine (and iron). Additions of 0.5 to 4.0 mg/L of chlorine caused increased susceptibility to impingement attack on C70600 at a velocity of 9 m/s (30 ft/s). Addition of chlorine up to 4.0 mg/L had little effect on the impingement resistance of C71500.

Polluted Cooling Waters. Polluted cooling waters, particularly in coastal harbors and estuaries, reportedly cause numerous premature failures of power station and shipboard condensers using copper-base alloys, including the copper nickels. During the early 1950s, polluted waters were identified as the most important contributing factor in the failure of condenser tubes.

The attack of copper-containing materials by polluted seawater has been addressed in numerous test programs. The primary causes of accelerated attack of copper-base alloys in polluted seawater are (1) the action of sulfate-reducing bacteria, under anaerobic conditions (for example, in bottom muds or sediments), on the natural sulfates present in seawater and (2) the putrefaction of organic sulfur compounds from decaying plant and animal matter with seawater systems during periods of extended shutdown. Partial putrefaction of organic sulfur compounds may also result in the formation of organic sulfides, such as cystine or glutathione, which can cause pitting of copper alloys in seawater.

A significant amount of work has recently been done on the behavior of copper alloys in sulfide-contaminated seawaters. Sulfides are added to the seawater by either bubbling hydrogen sulfide gas through the solution or by adding a sodium sulfide solution. In general, sulfide concentrations of the order of 1 ppm are sufficient to cause accelerated attack. For rapid corrosion to occur, the copper alloy must be exposed to a solution that contains oxygen as well as sulfide or must be alternately exposed to sulfide-bearing deaerated solutions, followed by exposure to sulfide-free aerated solutions. Alloy C70600 has been found to be susceptible to sulfide-induced attack in aerated seawater containing sulfide concentrations as low as 0.01 mg/L.

Lead. The corrosion of lead in seawater is relatively slight and may be retarded by encrustation's of lead salts. A study has shown that at the same tropical location (Panama Canal Zone) the corrosion rate of lead in seawater is about four times the rate in freshwater.

Nickel. Nickel 200 and alloy 400 and nickel-base alloys containing chromium and iron are very resistant to flowing seawater, but in stagnant or very low velocity seawater, pitting or crevice corrosion can occur, especially under fouling organisms or other deposits. In moderate- and high-velocity seawater or brackish water, alloy 400 is frequently used for pump and valve trim and transfer piping. It has excellent resistance to cavitation erosion and exhibits corrosion rates less than 0.025 mm/yr (1 mil/yr). Alloy 400 sheathing also provides economical seawater splash zone protection to steel offshore oil and gas platforms, pilings, and other structures. Although pitting can occur in alloy 400 under stagnant conditions, such pitting tends to slow down after fairly rapid initial attack and rarely exceeds 1.3 mm/yr (50 mils/yr) in depth. Age-hard-

ened alloy K-500, with corrosion resistance similar to that of alloy 400, is frequently used for high-strength fasteners and pump and propeller shafting in freshwater and seawater applications.

Other nickel-base alloys containing chromium and molybdenum offer increased resistance to localized corrosion in stagnant seawater. In hot seawater applications, such as heat exchangers, highly alloyed materials such as alloys 625 or C-276 may be required. In addition, alloys 625, 400, and K-500 are frequently specified for Naval wetted components in contact with seawater. Specific high tensile strength requirements are met will alloy 718.

Niobium. Niobium is resistant to attack in seawater.

Palladium. As an electrode for cathodic protection use in seawater, palladium corrodes at a rate of 8.6 g/A· yr at a current density of 540 A/m^2 (50 A/ft^2). The current efficiency is 0.05%. In binary palladium-platinum alloys, the corrosion rate in this application becomes equal to that of platinum if the palladium content is less than 20%.

Tantalum. Tantalum is not attacked by seawater, either cold or hot.

Tin. In some instances of marine use, the formation of a hard, crusty oxidation product has been observed on tin-rich bearings. When free access of salt water to a bearing is possible, the cathodic relationship of the babbitt alloys to steel renders them unsuitable, and bearing alloys such as Zn-70Sn-1.5Cu are preferred.

In seawater or uninhibited brines, the high conductivity and predominance of chloride makes galvanic action at a soldered joint more likely to continue destructively, and soldered joints in copper, nickel, and their alloys may need protection by coatings. Although tin or tin-coated metals can be used in contact with aluminum alloys even in salt water, the soldering process introduces sufficient aluminum to the solder to render it susceptible to intergranular corrosion. If tin-zinc solders are used, the zinc can prevent serious embrittling action, although some corrosion will still occur under moist conditions.

Titanium. Because of the hard, tenacious titanium dioxide surface film that forms on titanium in normal passive environments, both unalloyed titanium and titanium alloys can withstand flowing seawater at velocities as high as 30 m/s (100 ft/s) with insignificant metal loss. In fact, high-speed water wheel tests in seawater indicate erosion rates for grade 5 titanium of approximately 0.013 mm/yr (5 mils/yr) at 46 m/s (150 ft/s). Jet impingement tests also involving seawater velocities of 46 m/s (150 ft/s) reveal rates of 0.03 to 0.06 mm/yr (1.2 to 24 mils/yr) for commercially pure titanium, with values of approximately 0.03 mm/yr (1.2 mils/yr) for welded and unwelded grade 5 titanium samples. Extremely low erosion rates are also reported for grade 2 titanium at various seawater locations.

Studies involving sand and emery particle-laden seawater indicate satisfactory erosion-corrosion resistance to flow rates of approximately 6 m/s (20 ft/s). The immunity of titanium to erosion-corrosion in silt-laden seawater flowing at approximately 2 m/s (6.5 ft/s) has been demonstrated in more than 20 years of outstanding service in seawater for the chemical, oil refining, desalination, and power industries. As a result of its immunity to ambient seawater corrosion, titanium is considered to be the technically correct material for many critical marine applications, including many naval and offshore components. Exposure of titanium to marine atmospheres, splash or tide zone, and soils also does not cause corrosion.

In near-neutral electrolytes such as seawater, active metals such as zinc, magnesium, and aluminum can lead to hydrogen uptake and eventual embrittlement when coupled to titanium above 80 °C (175 °F).

Titanium alloys exhibit negligible corrosion rates in seawater up to temperatures as high as 260 °C (500 °F), and extremely low corrosion rates of both unalloyed titanium and Ti-6Al-4V after up to 3 years of exposure in ambient seawater have been recorded. Pitting and crevice corrosion are totally absent in ambient seawater, even if marine deposits form and biofouling occurs. Titanium tubing exposed for 16 years to polluted and sulfide-containing seawater shows no evidence of corrosion. Similar reports of nil corrosion rates in ambient seawater have been reported for unalloyed titanium and titanium alloys such as Ti-5Al-2Sn, Ti-13V-11Cr-3Al, Ti-6Al-2Nb-1Ta-0.8Mo, and titanium-palladium.

The outstanding resistance of titanium alloys to cavitation damage has also been documented, and it has been confirmed that the harder, higher strength titanium alloys are more resistant to cavitation.

Zinc. The corrosion behavior of zinc in seawater is determined by the amounts of dissolved salts, principally chlorides and sulfates, in the water. The high chloride content of seawater would normally tend to increase corrosion, but the presence of magnesium and calcium ions inhibits the attack. The effect of time of exposure on the corrosion rate in natural waters indicates that the corrosion rate in seawater initially exceeds that in freshwater, but after about 2 years of exposure, the rate in seawater decreases so that it is approximately the same as that in freshwater.

The frequency with which seaside piers and ship hulls require repainting testifies to the corrosivity of seawater and the importance of taking adequate protective measures. The salts present in the North Sea amount to about 3.5% of the total, mainly sodium chloride with smaller amounts of magnesium and calcium salts. This produces a solution with a pH of about 8.

The corrosion resistance of zinc compares favorably with that of other coating materials when totally immersed in seawater, possibly because of the slightly inhibitive action of the magnesium salts present. In tests, aluminum-, cadmium-, lead-, tin-, and zinc-coated specimens were immersed for 2 years. All except the zinc-coated specimens failed in this time. The zinc-coated specimens were then transferred to another test site and immersed for another 4 years. At the end of this time—a total of 6 years—the 915 g/m^2 (3 oz/ft^2) coatings were just ceasing to give complete protection to the basis steel. Therefore, it was concluded that the consumption of zinc is approximately 150 g/m^2 (0.5 oz/ft^2) of steel surface protected per year.

In most cases, zinc coatings would not be used alone when applied to steel immersed in seawater, but would form the first layer of a more elaborate protective system. Conditions within a few hundred yards of the surf line on beaches are intermediate between total immersion in seawater and normal exposure to a marine atmosphere. Such conditions have been studied in a series of tests carried out at Lighthouse Beach in Nigeria. At the high-water mark, about 45 m (50 yd) from the surf line on the tropical beach, conditions were extremely severe, and iron and zinc both corroded more rapidly than if they had actually been immersed in the sea.

Upon moving inland, however, it was found that both the salt content of the atmosphere and the rates of corrosion of iron and zinc fell off very rapidly. The values obtained only 1 km from the sea were similar to those obtained at inland sites.

Zirconium. Zirconium has excellent corrosion resistance in seawater, brackish water, and polluted water. Specimens with or without crevice attachment of Zr702 were placed in the Pacific Ocean at Newport, Oregon, for up to 129 days. All welded and nonwelded specimens exhibited negligible corrosion rates. Marine biofouling was observed; however, no corrosion was found beneath the marine organisms or within the crevices. Laboratory tests were performed on Zr702 and Zr704 in boiling seawater for 275 days and in 200 °C (390 °F) seawater for 29 days. Both alloys were resistant to general, pitting, and crevice corrosion.

Tests of U-bend specimens with or without steel coupling of Zr702, nickel-containing Zr704, and nickel-free Zr704 were conducted in boiling seawater for 365 days. No cracking was observed during the testing period. Overstressing of the tested U-bend specimens indicated that all specimens were still ductile, except for the welded nickel-containing Zr704 with steel coupling. Steel-coupled nickel-containing Zr704 showed much higher hydrogen and oxygen absorption and formed hydrides, particularly in the weld heat-affected zone. Chemical analyses and metallographic examinations on other U-bends did not show evidence of hydride formation.

Reference

1 G.S. Brady and H.R. Clauser, Ed., *Materials Handbook,* **11th ed., McGraw-Hill, New York, 1977**

Corrosion Behavior of Various Metals and Alloys in Seawater

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
5083-0	A95083	...	Half tide, North Carolina	...	...	10 yr	0.0009 (0.036)	Maximum depth of attack: 0.038 mils. Average depth of attack: 0.012 mils	150
5083-0	A95083	...	Immersion, North Carolina	...	...	10 yr	0.0015 (0.059)	Maximum depth of attack: 0.024 mils. Average depth of attack: 0.001 mils	150
5086-0	A95086	...	Half tide, North Carolina	...	...	10 yr	0.0009 (0.035)	Maximum depth of attack: 0.027 mils. Average depth of attack: 0.002 mils	150
5086-0	A95086	...	Immersion, North Carolina	...	...	10 yr	0.0015 (0.057)	...	150
5144-H38	A95144	...	Half tide, North Carolina	...	...	10 yr	0.0009 (0.037)	Maximum depth of attack: 0.020 mils. Average depth of attack: 0.005 mils	150
5154-H38	A95154	...	Immersion, North Carolina	...	...	10 yr	0.0014 (0.055)	...	150
5447-H34	A95447	...	Half tide, North Carolina	...	...	10 yr	0.0009 (0.036)	Maximum depth of attack: 0.022 mils. Average depth of attack: 0.001 mils	150
5454-H34	A95454	...	Half tide, North Carolina	...	...	10 yr	0.0010 (0.041)	Maximum depth of attack: 0.015 mils. Average depth of attack: 0.003 mils	150
5454-H34	A95454	...	Immersion, North Carolina	...	...	10 yr	0.0015 (0.059)	Maximum depth of attack: 0.020 mils. Average depth of attack: 0.004 mils	150
5456-0	A95456	...	Half tide, North Carolina	...	...	10 yr	0.0004 (0.014)	Maximum depth of attack: 0.069 mils. Average depth of attack: 0.013 mils	150
5456-0	...	...	Immersion, North Carolina	...	...	10 yr	0.0029 (0.116)	Maximum depth of attack: 0.131 mils. Average depth of attack: 0.040 mils	150
5456-H321	A95456	...	Half tide, North Carolina	...	...	10 yr	0.0013 (0.051)	Maximum depth of attack: 0.072 mils. Average depth of attack: 0.013 mils	150
5456-H321	A95456	...	Immersion, North Carolina	...	...	10 yr	0.0016 (0.064)	Maximum depth of attack: 0.044 mils. Average depth of attack: 0.012 mils	150

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
5456-H321	A95456	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.28 (11.0)	Pitting 14 mil (.35 mm)	226
5456-H321	A95456	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.28 (11.0)	Pitting 4 mil (.11 mm)	226
5457-H34	A95457	...	Immersion, North Carolina	...	...	10 yr	0.0014 (0.056)	...	150
Al-Mg_2Si alloys	...	...	...	...	...	...	Questionable	...	92
Alclad 2024-T3	...	...	At half tide	...	...	193 d	0.015 (0.6)	...	175
Aluminum (99.0-99.5%)	A91199	...	Half tide, North Carolina	...	...	10 yr	0.0009 (0.036)	Maximum depth of attack: 0.039 mils. Average depth of attack: 0.003 mils	150
Aluminum (99.0-99.5%)	A91199	...	Immersion, North Carolina	...	...	10 yr	0.0002 (0.061)	...	150
Carbon and alloy steels									
0.3 Cu steel	K12810	...	...	...	...	16 yr	...	Average depth, 2.2 (85)	149
0.3% Cu steel	K12810	...	...	...	...	1 yr	0.15 (5.9)	...	149
0.3% Cu steel	K12810	...	...	...	...	8 yr	0.09 (3.5)	...	149
0.3% Cu steel	K12810	...	...	...	...	16 yr	0.08 (3.1)	...	149
0.3% Cu steel	K12810	...	...	...	...	1 yr	...	Average depth, 0.9 (36)	149
0.3% Cu steel	K12810	...	...	...	...	8 yr	...	Average depth, 1.6 (63)	149
1.2Mn-0.75Ni-0.45Cu steel	...	...	North Carolina	...	...	1.5 yr	0.11 (4.4)	...	149
1.2Mn-0.75Ni-0.45Cu steel	...	...	North Carolina	...	...	2.5 yr	0.10 (3.8)	...	149
1.2Mn-0.75Ni-0.45Cu steel	...	...	North Carolina	...	...	4.5 yr	0.08 (3.0)	...	149
1.2Mn-0.75Ni-0.45Cu steel	...	...	North Carolina	...	...	8.5 yr	0.07 (2.6)	...	149
1.8Ni-0.81Cu	...	...	North Carolina	...	...	1.5 yr	0.14 (5.3)	...	149
1.8Ni-0.81Cu	...	...	North Carolina	...	...	2.5 yr	0.12 (4.5)	...	149
1.8Ni-0.81Cu	...	...	North Carolina	...	...	4.5 yr	0.09 (3.5)	...	149
1.8Ni-0.81Cu	...	...	North Carolina	...	...	8. yr	0.08 (3.2)	...	149
2 Ni steel	K21703	...	...	...	...	51 yr	0.19 (7.4)	...	149
2 Ni steel	K21703	...	...	...	...	8 yr	0.10 (4)	...	149
2 Ni steel	K21703	...	...	...	...	16 yr	0.09 (3.3)	...	149
2 Ni steel	K21703	...	...	...	...	1 yr	...	Average depth, 0.8 (33)	149
2 Ni steel	K21703	...	...	...	...	8 yr	...	Average depth, 2.4 (94)	149
2.6Cr-0.52Mo	...	...	North Carolina	...	...	1.5 yr	0.04 (1.4)	...	149
2.6Cr-0.52Mo	...	...	North Carolina	...	...	2.5 yr	0.04 (1.6)	...	149
2.6Cr-0.52Mo	...	...	North Carolina	...	...	4.5 yr	0.04 (1.6)	...	149
2.6Cr-0.52Mo	...	...	North Carolina	...	...	8.5 yr	0.03 (1.3)	...	149
4130	G41300	...	1.92% Cl^-, 690 kPa (100 psig). Plus CO_2 and 0.1% H_2S	...	175 (350)	...	2.6 (101)	...	172
4130	G41300	...	1.93% Cl^-, 690 kPa (100 psig). Plus CO_2, no H_2S	...	175 (350)	...	0.9 (35)	...	172
5 Cr steel	K41545	...	...	...	...	1 yr	0.07 (2.7)	...	149
5 Cr steel	K41545	...	...	...	...	8 yr	0.10 (4)	...	149
5 Cr steel	K41545	...	...	...	...	16 yr	0.09 (3.5)	...	149
5 Cr steel	K41545	...	...	...	...	1 yr	...	Average depth, 0.7 (27)	149

(Continued)

Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
5 Cr steel	K41545	...	...	...	...	8 yr	...	Average depth, 1.6 (63)	149
5 Cr steel	K41545	...	...	...	...	16 yr	...	Average depth, 1.8 (69)	149
5 Ni steel	...	...	...	...	...	8 yr	0.10 (4)	...	149
5 Ni steel	...	...	...	...	...	1 yr	0.16 (6.3)	...	149
5 Ni steel	...	...	...	...	...	16 yr	0.09 (3.3)	...	149
5 Ni steel	...	...	...	...	...	1 yr	...	Average depth, 0.7 (29)	149
5 Ni steel	...	...	...	...	...	8 yr	...	Average depth, 3.0 (117)	149
5Cr-1.5Mo	...	...	1.92% Cl^-, 690 kPa (100 psig). Plus CO_2 and 0.1% H_2S	...	175 (350)	...	1.0 (40)	...	172
5Cr-1.5Mo	...	...	1.93% Cl^-, 690 kPa (100 psig). Plus CO_2, no H_2S	...	175 (350)	...	0.03 (13)	...	172
ASTM A242, type 1	K11510	...	North Carolina	...	...	1.5 yr	0.11 (4.2)	...	149
ASTM A242, type 1	K11510	...	North Carolina	...	...	2.5 yr	0.11 (4.3)	...	149
ASTM A242, type 1	K11510	...	North Carolina	...	...	4.5 yr	0.10 (3.8)	...	149
ASTM A242, type 1	K11510	...	North Carolina	...	...	8.5 yr	0.08 (3.1)	...	149
Carbon steel	G10100	...	...	...	...	1 yr	...	Average depth, 1.0 (41)	149
Carbon steel	G10100	...	...	...	...	8 yr	...	Average depth, 1.7 (66)	149
Carbon steel	G10100	...	...	...	...	16 yr	...	Average depth, 2.3 (90)	149
Carbon steel	G10100	...	Flume (1.2 m/s)	...	...	...	0.33 (13)	...	171
Carbon steel	G10100	...	Panama Canal Zone	...	...	1 yr	0.15 (5.9)	...	149
Carbon steel	G10100	...	Panama Canal Zone	...	...	8 yr	0.08 (3.2)	...	149
Carbon steel	G10100	...	Panama Canal Zone	...	...	16 yr	0.08 (2.9)	...	149
Carbon steel	G10100	...	Rotating disk (8 m/s)	...	...	...	1.2 (47)	...	171
Carbon steel	G10100	...	Tidal current (0.3 m/s)	...	...	...	0.16 (6.2)	...	171
HY-80	...	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	1.02 (40.2)	Pitting 11 mil (.28 mm)	226
HY-80	...	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.90 (35.5)	Pitting 6 mil (.16 mm)	226
Structural carbon steel	G10100	...	North Carolina	...	...	1.5 yr	0.12 (4.8)	...	149
Structural carbon steel	G10100	...	North Carolina	...	...	2.5 yr	0.11 (4.1)	...	149
Structural carbon steel	G10100	...	North Carolina	...	...	4.5 yr	0.09 (3.3)	...	149
Structural carbon steel	G10100	...	North Carolina	...	...	8.5 yr	0.07 (2.7)	...	149
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	...	...	19-31 (66-88)	1 yr	0.005 (0.2)	...	227
70-30 cupronickel	C71500	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.004 (0.2)	0.1 mil (.002 mm)	227
70-30 cupronickel	C71500	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.015 (0.6)	0.6 mil (.015 mm)	227
70-30 cupronickel	C71500	...	Flowing Seawater	...	...	62 d	.0028 (0.11)	...	257
70-30 cupronickel	C71500	...	Flowing seawater with 0.25 ppm chlorine	...	...	62 d	.0025 (.010)	...	257
70-30 cupronickel	C71500	...	Flowing seawater with 0.5 ppm chlorine for 30 min every 8 h	...	...	62 d	.0020 (.08)	...	257

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
70-30 cupronickel	C71500	...	Flowing seawater with 0.5-1.0 ppm chlorine for 1 h every 6 h	...	...	62 d	.0020 (0.08)	...	257
70-30 cupronickel	C71500	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	...	0.12-1.08 (4.7-42.5)	173
70-30 cupronickel	C71500	...	Impingement test, (6.8 m/s)	...	10-26 (50-80)	30-60 d	...	0.36-6.84 (14.2-269)	173
70-30 cupronickel	C71500	...	Impingement test, (9.8 m/s)	...	10-26 (50-80)	30-60 d	...	1.68-2.04 (66-80.3)	173
70-30 cupronickel (modified)	C71900	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	Resistant	...	173
70-30 cupronickel (modified)	C71900	...	Impingement test, (6.8 m/s)	...	10-26 (50-80)	30-60 d	...	0.12-0.36 (4.7-14.2)	173
70-30 cupronickel (modified)	C71900	...	Impingement test, (9.8 m/s)	...	10-26 (50-80)	30-60 d	...	1.08-1.44 (42.5-56.7)	173
70Cu-30Ni	C71500	...	Flume (1.2 m/s)	...	...	...	0.01 (0.1) max	...	171
70Cu-30Ni	C71500	...	Rotating disk (8 m/s)	...	...	...	0.16 (6.3)	...	171
70Cu-30Ni	C71500	...	Tidal current (0.3 m/s)	...	...	...	0.01 (0.1) max	...	171
85-15 cupronickel + Cr	C72200	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	Resistant	...	173
85-15 cupronickel + Cr	C72200	...	Impingement test, (6.8 m/s)	...	10-26 (50-80)	30-60 d	...	0.12 (4.7)	173
85-15 cupronickel + Cr	C72200	...	Impingement test, (9.8 m/s)	...	10-26 (50-80)	30-60 d	Resistant	...	173
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	19-31 (66-88)	1 yr	0.005 (0.2)	...	227
90-10 cupronickel	C70600	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.010 (0.4)	<0.1 mil (.001 mm)	227
90-10 cupronickel	C70600	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.012 (0.5)	0.4 mil (.010 mm)	227
90-10 cupronickel	C70600	...	Flowing seawater	...	...	62 d	.0069 (0.27)	...	257
90-10 cupronickel	C70600	...	Flowing seawater with 0.25 ppm chlorine	...	...	62 d	.014 (0.55)	...	257
90-10 cupronickel	C70600	...	Flowing seawater with 0.5 ppm chlorine for 30 min every 8 h	...	...	62 d	.0071 (.28)	...	257
90-10 cupronickel	C70600	...	Flowing seawater with 0.5-1.0 ppm chlorine for 1 h every 6 h	...	...	62 d	.012 (0.47)	...	257
90-10 cupronickel	C70600	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	...	0.12-2.16 (4.7-8.5)	173
90-10 cupronickel	C70600	...	Impingement test, (6.8 m/s)	...	10-26 (50-80)	30-60 d	...	0.36-1.56 (14.2-61.4)	173
90-10 cupronickel	C70600	...	Impingement test, (9.8 m/s)	...	10-26 (50-80)	30-60 d	...	1.56 (61.4)	173
90Cu-10Ni	C70600	...	Rotating disk (8 m/s)	...	...	...	0.4 (16)	...	171
90Cu-10Ni	C70600	...	Tidal current (0.3 m/s)	...	...	...	0.02 (0.8)	...	171
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Admiralty Brass	C44300	...	Flowing seawater	...	...	62 d	.0074 (0.29)	...	257
Admiralty Brass	C44300	...	Flowing seawater with 0.25 ppm chlorine	...	...	62 d	.013 (0.51)	...	257
Admiralty brass	C44300	...	Flowing seawater with 0.5 ppm chlorine for 30 min every 8 h	...	...	62 d	.0099 (.39)	...	257
Admiralty brass	C44300	...	Flowing seawater with 0.5-1.0 ppm chlorine for 1 h every 6 h	...	...	62 d	.015 (.59)	...	257
Admiralty brass	C44300	...	Flume (1.2 m/s)	...	...	...	0.09 (3.4)	...	171
Admiralty brass	C44300	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	...	1.8-4.8 (71-189)	173
Admiralty brass	C44300	...	Rotating disk (8 m/s)	...	...	...	0.7 (29)	...	171
Admiralty brass	C44300	...	Tidal current (0.3 m/s)	...	...	...	0.01 (0.3)	...	171
Aluminum brass	C68700	...	Flowing Seawater	...	...	62 d	.0030 (0.12)	...	257
Aluminum brass	C68700	...	Flowing seawater with 0.25 ppm chlorine	...	...	62 d	.0066 (0.26)	...	257

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum brass	C68700	...	Flowing seawater with 0.5 ppm chlorine for 30 min every 8 h	...	...	62 d	.0036 (.41)	...	257
Aluminum brass	C68700	...	Flowing seawater with 0.5-1.0 ppm chlorine for 1 h every 6 h	...	...	62 d	.0018 (.07)	...	257
Aluminum brass	C68700	...	Impingement test, (4.6 m/s)	...	10-26 (50-80)	30-60 d	...	0.36-3 (14.2-118)	173
Aluminum brass	...	...	Rotating disk (8 m/s)	...	...	...	0.5 (18)	...	171
Aluminum brass	...	...	Tidal current (0.3 m/s)	...	...	...	0.01 (0.3)	...	171
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Aluminum bronze	C61800	...	Rotating disk (8 m/s)	...	...	...	1.0 (40)	...	171
Aluminum bronze	C61800	...	Tidal current (0.3 m/s)	...	...	...	0.02 (0.9)	...	171
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Copper	...	...	Half tide	...	...	193 d	0.013 (0.5)	...	175
Copper	...	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.12 (4.7)	Pitting 5 mil (.12 mm)	226
Copper	...	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.12 (4.7)	Pitting 5 mil (.12 mm)	226
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
G bronze	C90700	...	Flume (1.2 m/s)	...	...	...	(0.3)	...	171
G bronze	C90700	...	Rotating disk (8 m/s)	...	...	...	(45)	...	171
G bronze	C90700	...	Tidal current (0.3 m/s)	...	...	...	(1.1)	...	171
Hydraulic bronze	...	...	Flume (1.2 m/s)	...	...	...	(0.2)	...	171
Hydraulic bronze	...	...	Rotating disk (8 m/s)	...	...	...	(55)	...	171
Hydraulic bronze	...	...	Tidal current (0.3 m/s)	...	...	...	(0.7)	...	171
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze	...	...	Flume (1.2 m/s)	...	...	...	(0.3)	...	171
Silicon bronze	...	...	Rotating disk (8 m/s)	...	...	...	(60)	...	171
Silicon bronze	...	...	Tidal current (0.3 m/s)	...	...	...	(0.2)	...	171
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Iron and alloys									
Cast iron	F10001	...	Rotating disk (8 m/s)	...	...	...	1.3 (50)	...	171
Cast iron	F10001	...	Tidal current (0.3 m/s)	...	...	...	0.21 (8.2)	...	171
Miscellaneous									
Babbitt alloy (Sn-7.4Sb-3.7Cu)	...	...	North Carolina	...	...	1.4 yr	0.060 (2.4)	...	176
Lead	L50045	...	Bristol Channel	...	...	...	0.01 (0.5)	...	13
Lead	L50045	...	Bristol Channel 93% of the time	...	...	...	0.012 (0.5)	...	178

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead	L50045	...	Fort Amador, CZ. Tropical Pacific Ocean. Agitation: 0.5 ft/s. Flow: 150 m m/s	...	...	...	0.009 (0.36)	...	178
Lead	L50045	...	Fort Amador, CZ. Tropical Pacific Ocean. Flowing agitation at 150 m m/s (0.5 ft/s)	...	...	...	0.01 (0.4)	...	13
Lead	L50045	...	Fort Amador, CZ. Tropical Pacific Ocean. Mean tide level. Agitation: 0.5 ft/s. Flow: 150 m m/s	...	...	...	0.005 (0.02)	...	178
Lead	L50045	...	Fort Amador, CZ. Tropical Pacific Ocean. Mean tide level. Flowing agitation at 150 m m/s (0.5 ft/s)	...	...	...	0.005 (0.20)	...	13
Lead	L50045	...	Gatun Lake, CZ. Tropical fresh water. Agitation: still	...	...	...	0.002 (0.08)	...	178
Lead	L50045	...	North Carolina	...	...	...	0.015 (0.60)	...	13
Lead	L50045	...	North Carolina	...	...	...	0.015 (0.6)	...	178
Lead	L50045	...	Port Hueneme harbor, CA. Agitation: 0.2 ft/s; 60 m m/s maximum	...	...	...	0.005 (0.22)	...	178
Lead	L50045	...	Port Hueneme Harbor, CA. Flowing agitation at 60 m m/s (0.2 ft/s)	...	...	...	0.005 (0.22)	...	13
Lead	L50045	...	San Francisco Harbor. Mean tide level. Flowing agitation.	...	...	...	0.010 (0.42)	...	13
Lead	L50045	...	San Francisco harbor. seawater. Mean tide level. Agitation: flowing	...	...	...	0.01 (0.42)	...	178
Lead	L50045	...	Southhampton docks. Half tide level	...	...	...	0.01 (0.1) max	...	13
Lead	L50045	...	Southhampton docks. Half tide level	...	...	...	0.003 (0.11)	...	178
Magnesium	...	...	...	100	Room	...	Poor	...	119
Solder (Sn-50Pb)	L55030	Sheet	North Carolina	...	...	0.5 yr	0.075 (2.95)	...	176
Solder (Sn-60Pb on Cu)	L13600	Plate	North Carolina	...	...	2.1 yr	0.011 (0.43)	...	176
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin (99.2)	L13014	Cast bar	Bristol Channel	...	...	4 yr	0.01 (0.03) max	...	176
Tin (99.75)	L13008	Cast bar	Bristol Channel	...	...	4 yr	0.01 (0.09) max	...	176
Nickel and alloys									
Alloy 400	N04400	...	...	...	...	3 yr	...	Maximum pit depth: 1.067 mm (42 mils)	183
Alloy 400	N04400	...	...	...	19-31 (66-88)	1 yr	.025 (1.0)	1.2 mil (.030 mm)	227
Alloy 400	N04400	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.006 (0.2)	0.4 mil (.010 mm)	227
Alloy 400	N04400	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.023 (0.9)	0.8 mil (.020 mm)	227
Alloy 400	N04400	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.04 (1.6)	Crevice 5 mil (0.12 mm)	226
Alloy 400	N04400	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.03 (1.2)	Crevice 6 mil (.15 mm)	226
Alloy 625	N06625	...	...	...	...	3 yr	...	Maximum pit depth: nil	183
Alloy 625	N06625	...	...	...	19-31 (66-88)	1 yr	0.001 (0.04)	...	227
Alloy 625	N06625	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.002 (0.08)	...	227
Alloy 625	N06625	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.005 (0.2)	...	227

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	...	...	...	...	3 yr	...	Maximum pit depth: 0.025 mm (0.98 mils)	183
Alloy K-500	...	...	...	...	...	3 yr	...	Maximum pit depth: 0.864 mm (34 mils)	183
Cabot alloy No.625	N06625	...	Synthetic seawater	...	20 (68)	96 h	Resistant	...	67
Cabot alloy No.625	N06625	...	Synthetic seawater	...	35 (95)	96 h	Resistant	...	67
Cabot alloy No.625	N06625	...	Synthetic seawater	...	50 (122)	96 h	0.003 (0.1) max	...	67
Cabot alloy No.625	N06625	...	Synthetic seawater	...	65 (149)	96 h	0.003 (0.1) max	...	67
Cabot alloy No.625	N06625	...	Synthetic seawater	...	80 (176)	96 h	Resistant	...	67
Cabot alloy No.625	N06625	...	Synthetic seawater	...	90 (194)	96 h	Resistant	...	67
Hastelloy C	...	...	Rotating disk (8 m/s)	...	...	...	0.01 (0.4)	...	171
Hastelloy C	...	...	Tidal flow (0.3 m/s)	...	...	...	0.003 (0.1)	...	171
Incoloy 825	N08825	...	...	...	...	...	0.003 (0.1)	0.18 mm (7 mils) maximum; 0.03 mm (1 mil) average of five deepest areas. Crevice corrosion under barnacles	44
Incoloy 825	N08825	...	...	...	...	...	0.003 (0.1)	0.03 mm (1 mil) maximum; 0.03 mm (1 mil) average of five deepest areas	44
Inconel 600	N06600	...	At half tide	...	...	193 d	Resistant	...	175
Inconel 625	N06625	Circular weld	...	...	...	180 d	...	No stress corosion cracking	64
Inconel 625	N06625	Circular weld	...	...	...	365 d	...	No stress corosion cracking	64
Inconel 625	N06625	Circular weld	1¼- in. fiber washer bolted to center of panel face	...	...	180 d	...	None	64
Inconel 625	N06625	Circular weld	1¼- in. fiber washer bolted to center of panel face	...	...	180 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	1¼- in. fiber washer bolted to center of panel face	...	...	365 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	1¼- in. fiber washer bolted to center of panel face	...	...	365 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	Immersion in flowing seawater (2 ft/s). 1¼- in. fiber washer bolted to center of panel face	...	...	180 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	Immersion in flowing seawater (2 ft/s). 1¼- in. fiber washer bolted to center of panel face	...	...	180 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	Immersion in flowing seawater (2 ft/s). 1¼- in. fiber washer bolted to center of panel face	...	...	365 d	...	None, No stress corosion cracking	64
Inconel 625	N06625	Circular weld	Immersion in flowing seawater (2 ft/s). 1¼- in. fiber washer bolted to center of panel face	...	...	365 d	...	None, No stress corosion cracking	64
Monel 400	N04400	...	At half tide	...	...	193 d	0.025 (1)	...	175
Monel 400	N04400	...	Flume (1.2 m/s)	...	...	...	0.01 (0.2) max	...	171
Monel 400	N04400	...	Rotating disk (8 m/s)	...	...	...	0.02 (0.7)	...	171
Monel 400	N04400	...	Tidal current (0.3 m/s)	...	...	...	0.01 (0.2) max	...	171
Monel K-500	N05500	...	...	...	19-31 (66-88)	1 yr	.005 (0.2)	0.2 mil (.005 mm)	227
Monel K-500	N05500	...	1.92% Cl^-, 690 kPa (100 psig). Plus CO_2 and 0.1% H_2S	...	175 (350)	...	0.043 (2.7)	...	172

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel K-500	N05500	...	1.93% Cl^-, 690 kPa (100 psig). Plus CO_2, no H_2S	...	175 (350)	...	0.003 (0.12)	...	172
Monel K-500	N05500	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.004 (0.2)	0.9 mil (.022 mm)	227
Monel K-500	N05500	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.016 (0.6)	0.9 mil (.023 mm)	227
Refractory metals and alloys									
Hafnium	...	...	...	...	...	10 d	Resistant	...	11
Hafnium	...	...	...	...		10 d	Resistant	...	11
Tantalum	R05210	...	...	...	25 (76)	...	Resistant	...	42
Ti-6-4	R56400	...	...	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Ti-6-4	R56400	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Ti-6-4	R56400	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Titanium	...	...	...	...	24 (75)	...	Resistant	...	90
Titanium	...	...	...	...	Ambient	4.5 yr	Resistant	...	90
Titanium	...	...	Ocean depth: 1720 m (5640 ft)	...	...	...	0.001 (0.01) max	...	174
Titanium	...	...	Ocean depth: 2 to 2070 m (6.5 to 6800 ft)	...	...	...	Resistant	...	174
Titanium	...	...	Ocean depth: 720 to 2070 m (2360 to 6800 ft.)	...	...	...	0.003 (0.1) max	...	174
Titanium	...	...	Ocean depth: shallow	...	...	...	0.001 (0.01) max	...	174
Titanium	...	...	Rotating disk (8 m/s)	...	...	...	Resistant	...	171
Titanium	...	...	Tidal current (0.3 m/s)	...	...	...	Resistant	...	171
Titanium, grade 2	R50400	...	...	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Titanium, grade 2	R50400	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Titanium, grade 2	R50400	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.001 (0.04) max	...	227
Titanium, grade 5	R56400	...	Ocean depth: 1720 m (5640 ft)	...	Ambient	...	0.001 (0.04) max	...	185
Titanium, grade 5	R56400	...	Ocean depth: 2 to 2070 m (6.5 to 6800 ft)	...	Ambient	...	0.001 (0.04) max	...	185
Titanium, grade 9	...	...	...	...	Boiling	...	Resistant	...	33
Titanium, unalloyed	...	...	Ocean depth: 1720 m (5640 ft)	...	Ambient	...	0.001 (0.01) max	...	185
Titanium, unalloyed	...	...	Ocean depth: 2 to 2070 m (6.5 to 6800 ft)	...	Ambient	...	Resistant	...	185
Titanium, unalloyed	...	...	Ocean depth: 720 to 2070 m (2360 to 6800 ft)	...	Ambient	...	0.003 (0.1) max	...	185
Titanium, unalloyed	...	...	Ocean depth: shallow	...	Ambient	...	0.003 (0.1) max	...	185
Unalloyed titanium	...	...	Ocean depth: 1720 m (5640 ft)	...	...	...	0.001 (0.01) max	...	174
Unalloyed titanium	...	...	Ocean depth: 1720 m (5640 ft)	...	Ambient	...	0.001 (0.04) max	...	185
Unalloyed titanium	...	...	Ocean depth: 1720 m (5640 ft)	...	...	...	0.001 (0.04) max	...	174
Unalloyed titanium	...	...	Ocean depth: 2 to 2070 m (6.5 to 6800 ft)	...	...	...	0.001 (0.01) max	...	174
Zr702	R60702	...	...	...	Boiling	...	Resistant	...	62
Zr702	R60702	...	Pacific ocean	...	Boiling	...	Resistant	...	15
Zr702	R60702	...	Pacific ocean, pH 7.6	...	200 (390)	...	Resistant	...	15
Zr705	R60705	...	...	...	Boiling	...	Resistant	...	62
Zr705	R60705	...	Pacific ocean	...	Boiling	...	Resistant	...	15
Stainless steels									
20Cb-3	N08020	...	...	...	30 (86)	30 d	...	41% crevices initiated 3.1 (122)	60

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
254SMO	S31254	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	0.19 (7.5 mils)	184
254SMO	S31254	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	0.19 (7.5 mils)	184
254SMO	S31254	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	0.19 (7.5 mils)	184
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	...	Boiling	...	Questionable	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	Boiling	...	Questionable	Pitting	253
302	S30200	...	At half tide	...	...	193 d	0.01 (0.1) max	...	175
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	Boiling	...	Questionable	Pitting	253
304	S30400	...	...	...	...	...	...	Perforated (3 mm). Crevice corrosion under barnacles and at sheared edges	44
304	S30400	...	...	...	...	...	...	3.02 mm (119 mils) maximum; 1.07 mm (42 mils); average of five deepest areas. Crevice corrosion under barnacles and at sheared edges	44
304	S30400	Pickled in HNO_3HF	...	...	...	320 d	...	Maximum pitting 0.89 mm, 0.035 in., maximum crevice attack 0.9 mm, 0.036 in.	
304	S30400	...	...	...	19-31 (66-88)	1 yr	.003 (0.1)	...	227
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	Boiling	...	Questionable	Pitting	253
304	S30400	...	Chlorinated at 1 ppm TO	...	19-31 (66-88)	1 yr	.003 (0.1)	0.1mil (.003 mm)	227
304	S30400	...	Chlorinated at 4 ppm TO	...	19-31 (66-88)	1 yr	.012 (0.5)	0.9mil (.024 mm)	227
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	...	Boiling	...	Questionable	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Questionable	Pitting	253
308	S30800	Hot rolled, No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	955 d	...	Maximum pitting 5.2 mm, 0.205 in., maximum crevice attack 3.6 mm, 0.141 in.	
309	S30900	Pickled in HNO_3 HF	...	...	...	320 d	...	Maximum pitting 0.51 mm, 0.020 in., maximum crevice attack 1.4 mm, 0.055 in.	
310	S31000	Pickled in HNO_2 HF	...	...	...	320 d	...	Maximum pitting 0.15 mm, 0.006 in., maximum crevice attack 0.6 mm, 0.024 in.	

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	...	...	...	...	1.83 mm (72 mils); 1.27 mm (50 mils) average of five deepest areas. Crevice corrosion under barnacles and at sheared edges	44
316	S31600	...	...	...	...	...	...	1.52 mm (60 mils) maximum; 1.14 mm (45 mils) average of five deepest areas. Crevice corrosion under barnacles and at sheared edges.	44
316	S31600	...	...	...	14 (57)	29 d	...	81% crevices initiated. 1.2 (47)	60
316	S31600	...	...	...	30 (86)	30 d	...	28% crevices initiated. 1.9 (75)	60
316	S31600	...	...	...	52 (126)	30 d	...	28% crevices initiated. 0.10 (4)	60
316	S31600	...	...	...	...	3 yr	...	Maximum pit depth: 1.6 mm (62 mils)	183
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	At half tide	...	...	193 d	Resistant	...	175
316	S31600	Hot rolled, welded, ½ pickled, ½ No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	944 d	...	Maximum pitting 0.18 mm 0.007 in., maximum crevice attack 0.25 mm, 0.010 in.	
316	S31600	Hot rolled, pickled	Flowing seawater 0.3-0.6 m/s	...	...	1255 d	...	Maximum pitting 1.3 mm, 0.050 in., maximum crevice attack 4.3 mm, 0.170 in.	
316	S31600	...	Flume (1.2 m/s)	...	...	...	Resistant	...	171
316	S31600	...	Rotating disk (8 m/s)	...	...	...	0.01 (0.2) max	...	171
316	S31600	...	Tidal current (0.3 m/s)	...	...	...	0.01 (0.2) max	...	171
316	S31600	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.03 (1.2)	Crevice 7mil (.19 mm)	226
316	S31600	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.04 (1.6)	Crevice 13mil (.32 mm)	226
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	Boiling	...	Questionable	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Good	Pitting	253
317	S31700	...	...	...	30 (86)	30 d	1.9 (75)	76% crevices initiated 1.9 (7.5)	60
317	S31700	Hot rolled, No. 4 finish	...	...	...	1075 d	...	Maximum pitting 0.58 mm, 0.023 in., maximum crevice attack 1.1 mm, 0.045 in.	
317L	S31725	...	...	...	30 (86)	30 d	...	97% crevices initiated 1.1 (43)	60
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	Boiling	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Good	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	Boiling	...	Questionable	Pitting	253
321	S32100	Hot rolled, welded, ½ pickled, ½ No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	944 d	...	Maximum pitting 1.35 mm 0.053 in., maximum crevice attack 1.4 mm, 0.056 in.	
325	S32500	Hot rolled, pickled, No. 4 finish	...	...	...	106 d	...	Maximum pitting 0.81 mm, 0.032 in., maximum crevice attack none, none	
325	S32500	Hot rolled, pickled, No. 1 finish	...	...	...	106 d	...	Maximum pitting 1.4 mm, 0.056 in., maximum crevice attack none, none	
329	S32900	Mill-finished	...	...	30 (86)	30 d	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 Nm (25 or 75 in. lb). Maximum crevice attack 1.6 mm (63 mils)	184
329	S32900	Mill-finished	...	...	30 (86)	30 d	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 Nm (25 or 75 in.lb). Maximum crevice attack 1.6 mm (63 mils)	184
329	S32900	Mill-finished	...	...	30 (86)	30 d	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 Nm (25 or 75 in. lb). Maximum crevice attack 1.6 mm (63 mils)	184
329	S32900	Hot rolled, pickled, No. 4 finish	...	...	...	106 d	...	Maximum pitting 0.0 mm, 0.000 in., maximum crevice attack 0.25 mm, 0.010 in.	
329	S32900	Hot rolled, pickled, No. 1 finish	...	...	...	106 d	...	Maximum pitting 0.0 mm, 0.000 in., maximum crevice attack 0.9 mm, 0.037 in.	
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	Boiling	...	Good	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	Boiling	...	Questionable	Pitting	253
347	S34700	Hot rolled, No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	755 d	...	Maximum pitting 3.8 mm, 0.148 in., maximum crevice attack 1.55 mm, 0.061 in.	
347	S34700	Hot rolled, pickled	Flowing seawater 0.3-0.6 m/s	...	...	755 d	...	Maximum pitting 2.0 mm, 0.079 in., maximum crevice attack 1.2 mm, 0.047 in.	

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Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	Hot rolled, No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	388 d	...	Maximum pitting 1.9 mm, 0.075 in., maximum crevice attack 1.2 mm, 0.046 in.	
405	S40500	Hot rolled, No. 4 finish	Flowing seawater 0.3-0.6 m/s	...	...	755 d	...	Maximum pitting 2.5 mm 0.100 in., maximum crevice attack 4.75 mm, 0.187 in.	
410	S41000	...	1.92% Cl^-, 690 kPa (100 psig). Plus CO_2 and 0.1% H_2S	...	175 (350)	...	0.03 (1.0)	...	172
410	S41000	...	1.92% Cl^-, 690 kPa (100 psig). Plus CO_2 and 0.1% H_2S	...	175 (350)	...	0.03 (1.2)	...	172
410	S41000	...	1.93% Cl^-, 690 kPa (100 psig). Plus CO_2, no H_2S	...	175 (350)	...	0.04 (1.4)	...	172
430	S43000	...	...	...	20 (68)	...	Resistant	Pitting	253
430	S43000	Hot rolled, pickled	Flowing seawater 0.3-0.6 m/s	...	...	568 d	...	Maximum pitting 3.4 mm, 0.135 in., maximum crevice attack 1.85 mm, 0.072 in.	
434	S43400	...	...	...	20 (68)	...	Resistant	Pitting	253
AL-29-4C	S44735	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	nil	184
AL-29-4C	S44735	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	nil	184
AL-29-4C	S44735	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	nil	184
AL-6X	N08366	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	0.34 mm (13.4 mils)	184
AL-6X	N08366	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	0.34 mm (13.4 mils)	184
AL-6X	N08366	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	0.34 mm (13.4 mils)	184
Alloy 904L	N08904	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	Maximum crevice attack: 0.37 mm (14.6 mils)	184
Alloy 904L	N08904	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb).	...	30 (86)	60 d	...	Maximum crevice attack: 0.37 mm (14.6 mils)	184
Alloy 904L	N08904	...	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	Maximum crevice attack: 0.37 mm (14.6 mils)	184
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	Boiling	...	Good	Pitting	253
Ferralium 255	S32550	...	...	...	20 (68)	...	Resistant	...	60
Ferralium 255	S32550	...	...	...	35 (95)	...	Resistant	...	60

(Continued)

Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ferralium 255	S32550	...	...	...	50 (122)	...	0.01 (0.1) max	...	60
Ferralium 255	S32550	...	...	...	65 (149)	...	0.01 (0.1) max	...	60
Ferralium 255	S32550	...	...	...	80 (175)	...	Resistant	...	60
Ferralium 255	S32550	...	...	...	90 (194)	...	Resistant	...	60
Ferralium 255	S32550	...	...	...	14 (57)	29 d	...	No crevices initiated. <0.01 (0.4)	60
Ferralium 255	S32550	...	...	...	30 (86)	30 d	...	1.6% crevices initiated. <0.08 (3.1)	60
Ferralium 255	S32550	...	...	...	52 (126)	30 d	...	0.8% crevices initiated. <0.01 (0.4)	60
Ferralium 255	S32550	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	Maximum crevice attack: 0.09 mm (3.5 mils)	184
Ferralium 255	S32550	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	Maximum crevice attack: 0.09 mm (3.5 mils)	184
Ferralium 255	S32550	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	Maximum crevice attack: 0.09 mm (3.5 mils)	184
Ferralium 255	S32550	...	Saturated with Cl gas. Average of duplicate, smooth specimens	...	20 (68)	96 h	0.05 (2)	...	60
Ferralium 255	S32550	...	Saturated with Cl gas. Average of duplicate, smooth specimens	...	35 (95)	96 h	0.02 (0.8)	...	60
Ferralium 255	S32550	...	Saturated with Cl gas. Average of duplicate, smooth specimens	...	65 (149)	96 h	0.18 (7)	...	60
Ferralium 255	S32550	...	Seawater saturated with SO_2 gas	...	66 (150)	...	Resistant	...	60
Ferralium 255	S32550	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.01 (0.4) max	...	226
Ferralium 255	S32550	...	Velocity 7.9FPS (2.4 m/s)	...	27 (80)	42 d	0.01 (0.4) max	...	226
MONIT	S44635	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	0.01 mm (0.4 mils)	184
MONIT	S44635	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	0.01 mm (0.4 mils)	184
MONIT	S44635	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	0.01 mm (0.4 mils)	184
Nitronic 50	S20910	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	1.2 mm (47.2 mils)	184
Nitronic 50	S20910	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	60 d	...	1.2 mm (47.2 mils)	184
Nitronic 50	S20910	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	90 d	...	1.2 mm (47.2 mils)	184
Sea-Cure	S44660	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N · m (25 or 75 in. · lb)	...	30 (86)	30 d	...	0.11 mm (4.3 mils)	184

(Continued)

Corrosion Behavior of Various Metals and Alloys in Seawater (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Sea-Cure	S44660	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N·m (25 or 75 in.·lb)	...	30 (86)	60 d	...	0.11 mm (4.3 mils)	184
Sea-Cure	S44660	Mill-finished	Filtered seawater flowing at <0.1 m/s (<0.33 ft/s); crevice washers tightened to 2.8 or 8.5 N·m (25 or 75 in.·lb)	...	30 (86)	90 d	...	0.11 mm (4.3 mils)	184

Ratings of Some Metals for Resistance to Cavitation Erosion in Seawater

Group 1: Most resistant. Subject to little or no damage. Useful under extremely severe conditions

Stellite hardfacing alloys
Titanium alloys
Austenitic and precipitation-hardening stainless steels
Nickel-chromium alloys such as Inconel alloys 625 and 718
Nickel-molybdenum-chromium alloys such as Hastelloy C

Group II: These metals are commonly used where a high order of resistance to cavitation damage is required. They are subject to some metal loss under the most severe conditions of cavitation.

Nickel-copper-aluminum alloy Monel K-500
Nickel-copper alloy Monel 400
Copper alloy C95500 (nickel-aluminum bronze, cast)
Copper alloy C95700 (nickel-aluminum-manganese bronze, cast)

Group III: These metals have some degree of cavitation resistance. They are generally limited to low-speed low-performance applications.

Copper alloy C71500 (copper-nickel, 30% Ni)
Copper alloys C92200 and C92300 (leaded tin bronzes M and G, cast)
Manganese bronze, cast
Austenitic nickel cast irons

Group IV: These metals normally are not used in applications where cavitation damage may occur, except in cathodically inhibited solutions or when protected by elastomeric coatings.

Carbon and low-alloy steels
Cast irons
Aluminum and aluminum alloys

(a) Applies to normal cavitation-erosion intensities, at which corrosion resistance has a substantial influence on the resistance to damage.

Source: A.H. Tuthill and C.M. Schillmoler, Guidelines for Selection of Marine Materials, in *Ocean Science and Science Engineering Conference,* Marine Technology Society, Washington, June 1965.

Corrosion of Stainless Steels in Flowing Seawater

				Depth of pitting								
				Surface				Under Bakelite washers				
				Maximum		Average(b)		Maximum		Average(b)		
Type(a)	Original surface condition	Test period, days	Weight loss, g	mm	in.	mm	in.	mm	in.	mm	in.	Condition of edge
405	Hot rolled, No. 4 finish	755(c)	135	2.5	0.100	1.5	0.059	4.75(d)	0.187(d)	2.6	0.103	Badly pitted
403	Hot rolled, No. 4 finish	388(c)	118	1.9	0.075	1.0	0.038	1.2(e)	0.046(e)	1.0	0.040	Badly pitted
430	Hot rolled, pickled	568(c)	109	3.4	0.135	1.45	0.057	1.85(e)	0.072(e)	1.55	0.061	Badly pitted
308	Hot rolled, No. 4 finish	755(c)	28	5.2	0.205	2.1	0.083	3.6	0.141	1.7	0.066	Badly pitted
347	Hot rolled, No. 4 finish	755(c)	26	3.8	0.148	1.5	0.59	1.55	0.061	1.2	0.046	Badly pitted
	Hot rolled, pickled	755(c)	30	2.0	0.079	1.4	0.054	1.2	0.047	1.0	0.038	Few pits
321	Hot rolled, welded, 1/2 pickled, 1/2 No. 4 finish	944	...	1.35(f)	0.053(f)	0.38	0.015	1.4	0.056	0.6	0.024	No pitting
316	Hot rolled, welded, 1/2 pickled, 1/2 No. 4 finish	944	...	0.18	0.007	1 pit	1 pit	0.25	0.010	0.08	0.003	No pitting
	Hot rolled, pickled	1255	3	1.3	0.050	0.56	0.022	4.3	0.170	1.2	0.046	No pitting
317	Hot rolled, No. 4 finish	1075	5	0.58	0.023	0.30(g)	0.012(g)	1.1	0.045	0.7	0.027	Pitted
304	Pickled in HNO_3-HF	320	12	0.89	0.035	0.56	0.022	0.9	0.036	0.6	0.024	No pitting
309	Pickled in HNO_3-HF	320	11	0.51	0.020	0.30	0.012	1.4(d)	0.055(d)	1.4(d)	0.055(d)	No pitting
310	Pickled in HNO_2-HF	320	4	0.15	0.006	0.08	0.003	0.6(d)	0.024(d)	0.6(d)	0.024(d)	No pitting
325	Hot rolled, pickled, No. 4 finish	106	15	0.81	0.032	0.18	0.007	None	None	None	None	Grooved to 1.3 mm (0.05 in.)
	Hot rolled, pickled, No. 1 finish	106	60	1.4	0.056	1 pit	1 pit	None	None	None	None	Grooved to 2.5 mm (0.10 in.)
329	Hot rolled, pickled, No. 4 finish	106	0	0.0	0.000	0.0	0.000	0.25	0.010	2 pits	2 pits	No pitting
	Hot rolled, pickled, No. 1 finish	106	7	0.0	0.000	0.0	0.000	0.9	0.037	2 pits	2 pits	No pitting

(a) Panels 305 by 305 mm (12 by 12 in.) were completely immersed at Kure Beach, North Carolina, in seawater flowing at 0.3 to 0.6 m/s (1 to 2 ft/s). (b) These values are averages of the ten deepest pits. (c) Specimens withdrawn from test due to failure in period indicated. (d) Specimen became perforated. (e) Local attack directly under washer; holes were greatly enlarged. (f) One pit in weld, 3.2 mm (0.125 in.) deep. (g) Five pits.

Source: *Metals Handbook*, 9th ed., Vol 3, Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, American Society for Metals, Metals Park, OH, 1980, 71.

Galvanic Series of Some Commercial Metals and Alloys in Seawater

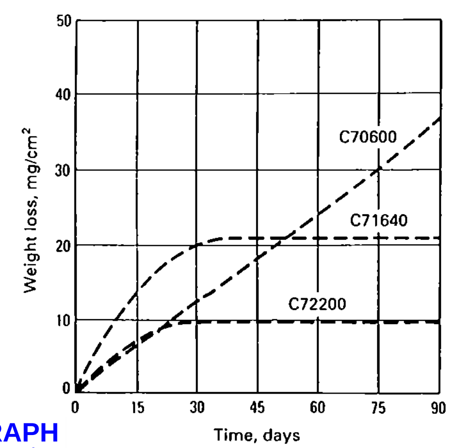
Active or anodic (-)

- Magnesium
- Magnesium alloys
- Zinc
- Galvanized steel
- Aluminum 1100
- Aluminum 2024 (4.5% Cu, 1.5% Mg, 0.6%Mn)
- Mild steel
- Wrought iron
- Cast iron
- 13% chromium stainless steel
  - Type 410 (active)
- 18-8 stainless steel
  - Type 304 (active)
- Lead-tin solders
- Lead
- Tin
- Muntz metal
- Manganese bronze
- Naval brass
- Nickel (active)
- 76Ni-16Cr-7Fe alloy (active)
- 60Ni-30Mo-6Fe-1Mn
- Yellow brass
- Admiralty brass
- Red brass
- Copper
- Silicon bronze
- 70-30 cupronickel
- G-bronze
- Silver solder
- Nickel (passive)
- 76Ni-16Cr-7Fe
  - Alloy (passive)
- 13% chromium stainless steel
  - Type 410 (passive)
- Titanium
- 18-8 stainless steel
  - Type 304 (passive)

Noble or cathodic (+)

- Silver
- Graphite
- Gold
- Platinum

Source: *NACE Corrosion Basics*, National Association of Corrosion Engineers, Houston, 1984.



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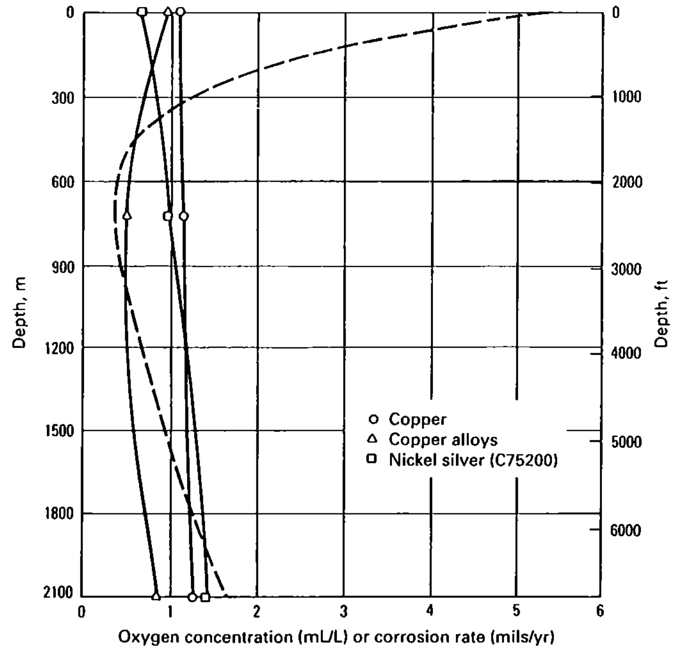
Copper. Weight loss vs. time curves for C70600, C71640, and C72200 exposed in seawater at a velocity of 9 m/s (40 ft/s). Source: C. Pearson, *British Corrosion Journal*, Vol 7, March 1972.



Copper. Corrosion of copper alloys vs. depth after 1 year of exposure compared to the shape of the dissolved oxygen profile (dashed line). Source: F.L. LaQue, *Marine Corrosion*, Wiley-Interscience, New York, 1975.

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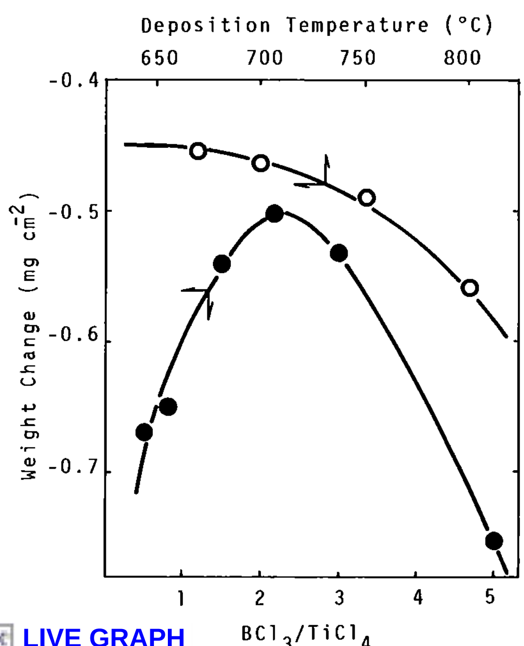

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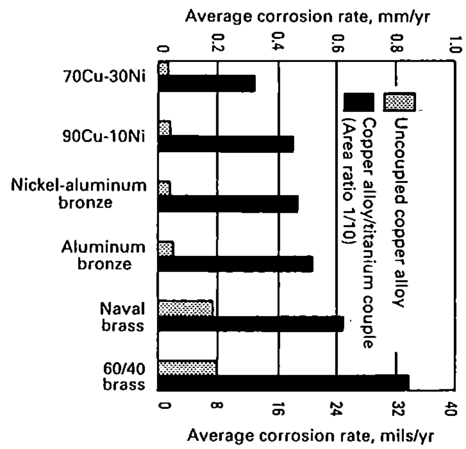
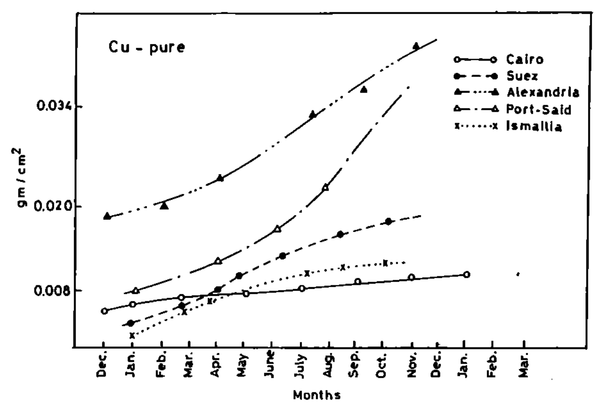
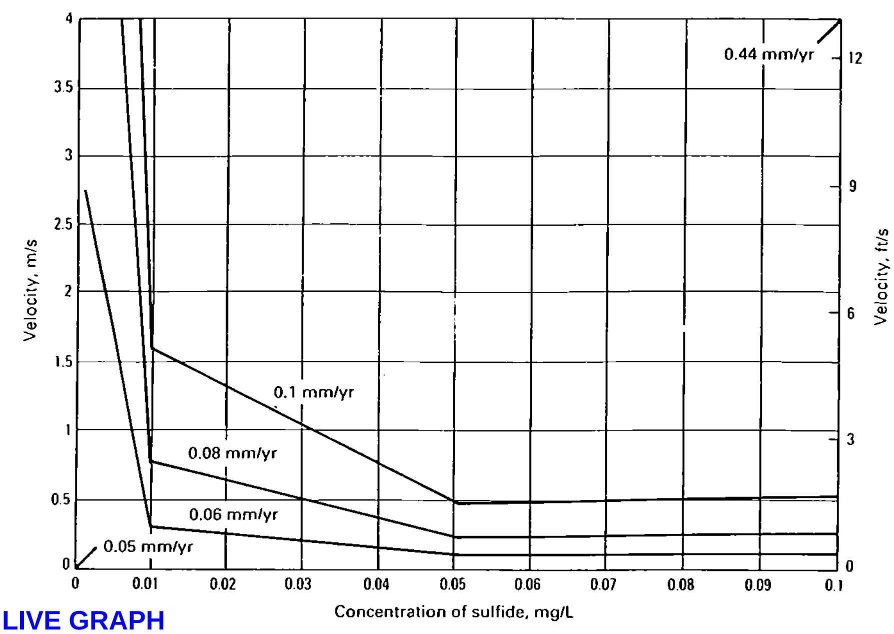
Copper. Effect of deposition temperature and gas-flow ratio ($BCl_3/TiCl_4$) on weight change of copper plate coated with CVD TiB_2 in seawater. Temperature of seawater, 33 °C; immersion time, 175 h. Open circle: gas-flow ratio ($BCl_3/TiCl_4$), 2.25; thickness of coated layer 1.0 μm. Closed circle: deposition temperature, 800 °C; thickness of coated layer, 0.7 μm. Source: S. Motojima and H. Kosaki, "Resistivities Against Seawater Corrosion and Sea-Sands Abrasion of TiB_2-Coated Copper Plate," *Journal of Materials Science Letters*, Vol 4, Nov 1985, 1351.



Copper. Corrosion of various copper alloys that were galvanically coupled to titanium in aerated seawater at 25 °C (77 °F). Source: T. Fukuzuka, K. Shimogori, H. Satoh, and F. Kamikubo, "Corrosion Problems and Countermeasures in MSF Desalination Plant Using Titanium Tube," Kobe Steel Ltd., 1985.



Copper. Weight loss vs. time of exposure for copper. Source: A.A. Ishmail, N.A. Khanem, *et al.*, "A Corrosion Map of Cairo and the Coastal Area of Egypt," *Corrosion Prevention and Control*, Vol 32, Aug 1985, 77.



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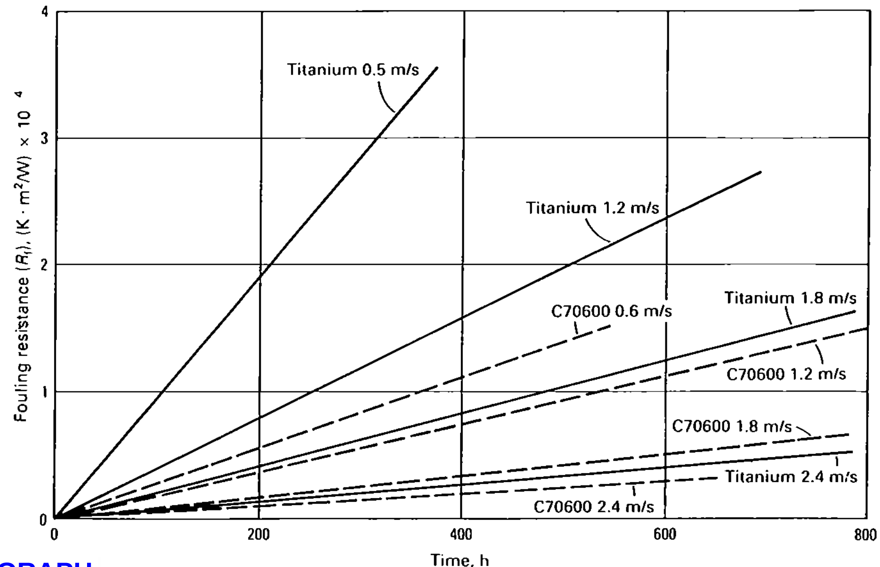
Copper. Corrosion rates of C70600 as a function of seawater velocity and sulfide content. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 625.



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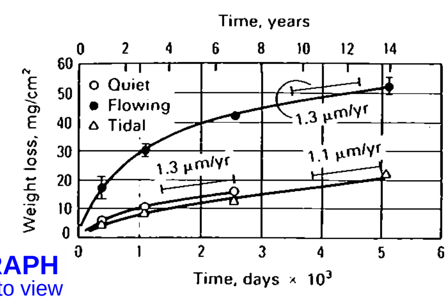
Copper. Fouling rates of C70600 and titanium as a function of seawater velocity. Source: R.B. Ritter and J.W. Suitor, "Fouling Research on Copper and Its Alloys—Seawater Studies," Progress Report, Project 214B, International Copper Research Association, March 1976 to Feb 1978.



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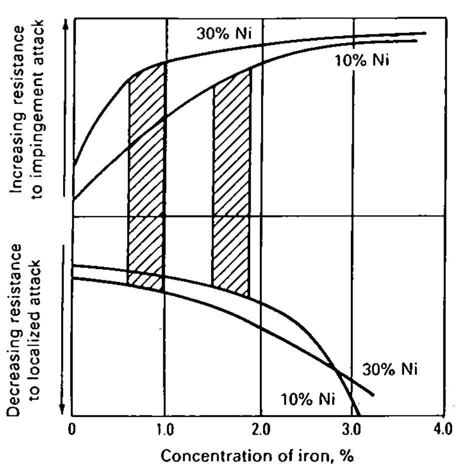
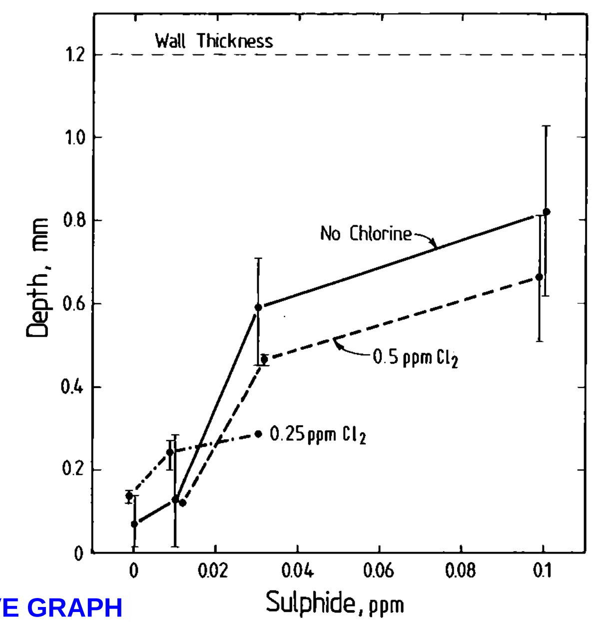
Copper. Chronogravimetric curves for C70600 in quiet, flowing, and tidal seawater. Source: K.D. Efird and D.B. Anderson, *Materials Performance*, Vol 14 (No. 11), 1975.



Copper-nickel alloys. Corrosion resistance of copper-nickel alloys as a function of iron content. Shaded areas indicate optimum iron contents for good balance between pitting resistance and impingement resistance. Source: C. Pearson, *British Corrosion Journal*, Vol 7, March 1972.



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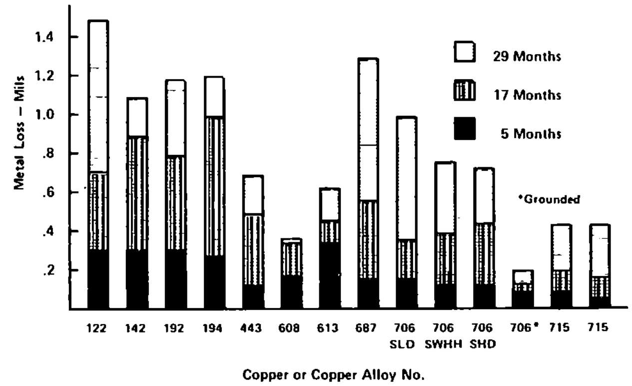
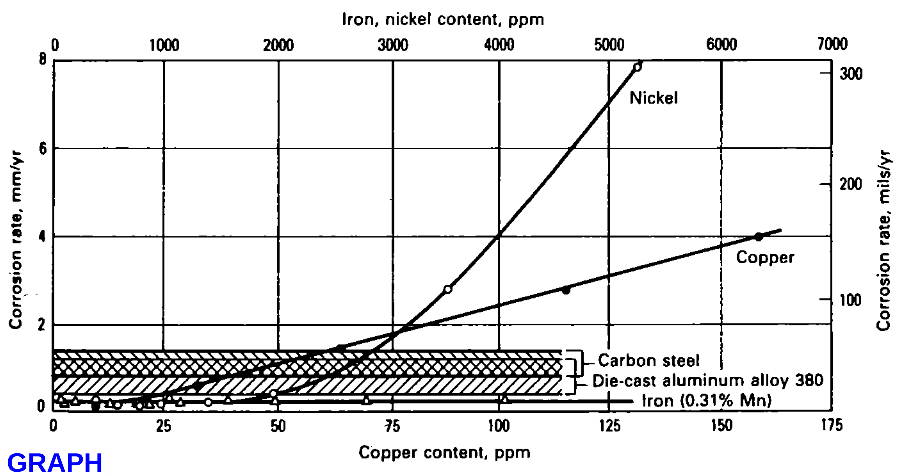
Copper alloy. Depth of impingement zone attack on 70Cu-30Ni as function of water chlorine and sulfide levels in seawater. Source: R. Francis, "Effect of Pollutants on Corrosion of Copper Alloys in Sea Water," *British Corrosion Journal*, Vol 20, July 1985, 178.



Copper alloys. Metal loss after 5, 17, and 29 months in a recycle brine exchanger. Source: A. Cohen, "Copper Alloys in Marine Environments," in *Source Book on Copper and Copper Alloys*, American Society for Metals, Metals Park, OH, 1979, 344.



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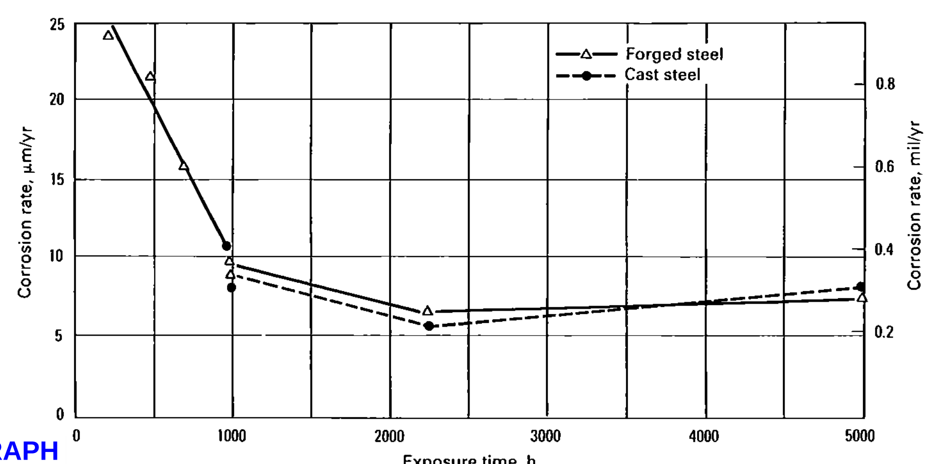
AZ91. Effect of nickel and copper contamination on the salt spray corrosion performance of die-cast AZ91 alloy. Source: J.E. Hillis and K.N. Reichek, Paper 860288, Society of Automotive Engineers, 1986.



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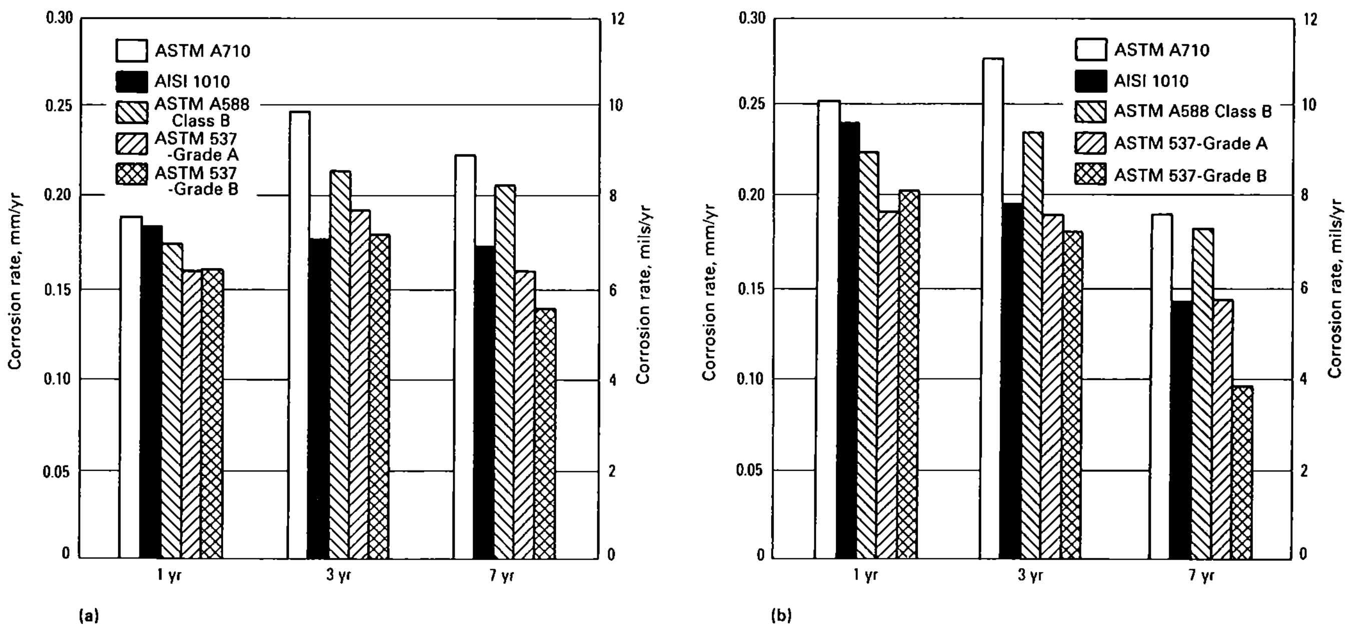
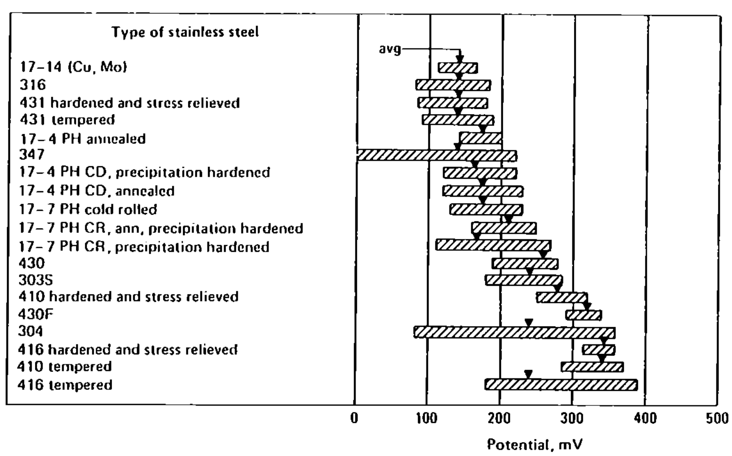
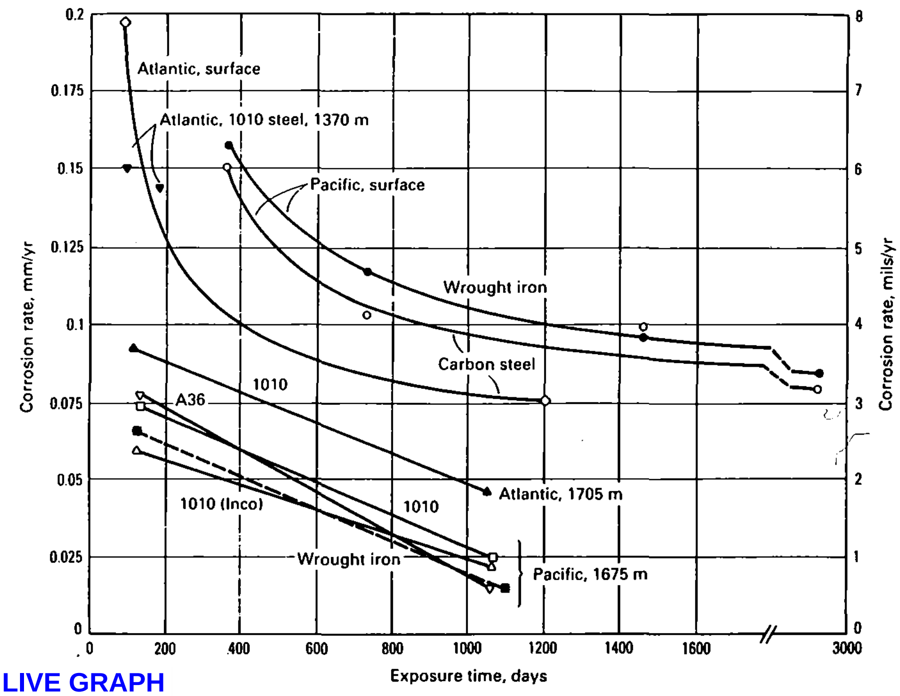
Low-alloy steels. Effect of time on the general corrosion of low-alloy steels in deaerated seawater at 90 °C (195 °F). Source: G.P. Marsh, "Influence of Temperature and Pressure on the Behaviour of High Level Waste and Canister Materials Under Marine Disposal Conditions," Part 2, Report S.P. 1.07.C2.85.51, Commission of European Communities, Dec 1985, 1, 15-27.



Steel. Corrosion results for ASTM A710 and other steels exposed to (a) low velocity (0.5 m/s or 1.6 ft/s) seawater and (b) quiet (still) seawater. Source: D.G. Melton and D.G. Tipton, Corrosion Behavior of A710 Grade A Steel in Marine Environments, LaQue Center for Corrosion Technology Inc., Wrightsville Beach, NC, June 1983.



Stainless steels. Corrosion potentials of stainless steels in flowing seawater. Corrosion potentials vs. saturated calomel electrode in seawater flowing at 4 m/s (13 ft/s) vary with composition and condition of the stainless steels. Temperature for these tests was 18 to 29 °C (64 to 84 °F). Source: *Metals Handbook*, 9th ed., Vol 3, Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, American Society for Metals, Metals Park, OH, 1980, 74.



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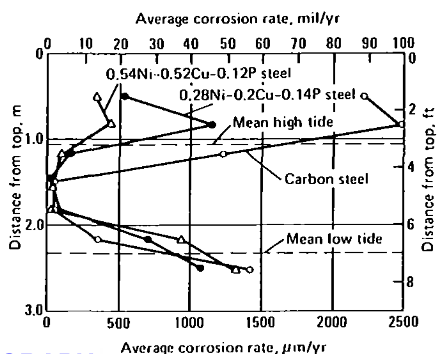
Carbon steels. Splash-zone and tidal-zone corrosion of carbon steel and two Ni-Cu-P steels. Source: C.V. Brouillette and A.E. Hanna, "Second Corrosion Survey of Steel Sheet Piling," U.S. Naval Civil Engineering Laboratory, 1965.



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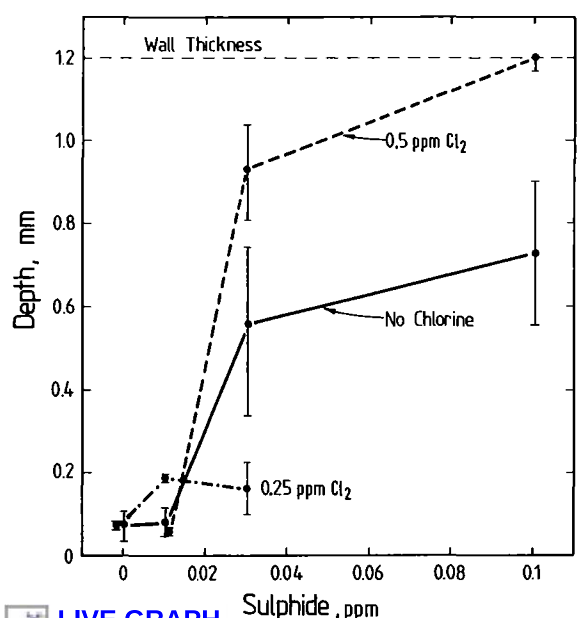
Carbon steel and wrought iron. Corrosion rates of carbon steel and wrought iron in the Atlantic and Pacific Oceans at various depths. Source: F.W. Fink and W.K. Boyd, Corrosion of Metals in Marine Environments, MCIC Report No. 78-37, Metals and Ceramics Information Center, Battelle Columbus Laboratories, Columbus, OH, 1978.



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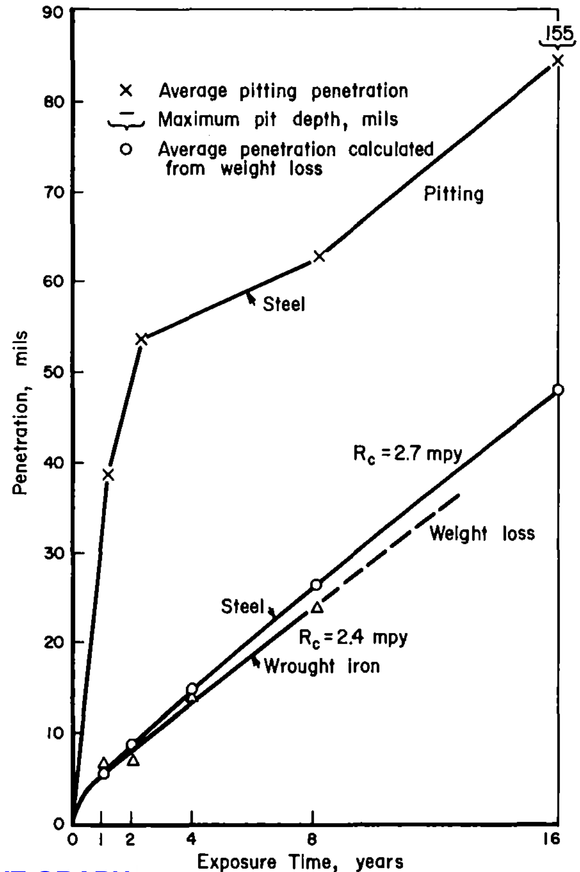
Aluminum brass. Depth of impingement zone attack on aluminum brass as a function of water chlorine and sulfide levels in seawater. Source: R. Francis, "Effect of Pollutants on Corrosion of Copper Alloys in Sea Water," *British Corrosion Journal*, Vol 20, July 1985, 177.



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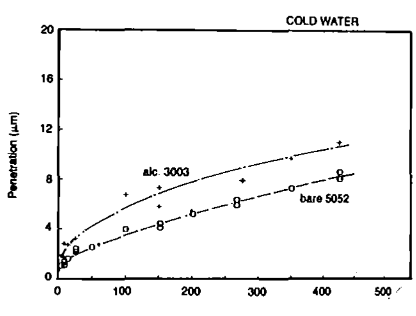
Carbon steel and wrought iron. Corrosion of carbon steel and wrought iron continuously immersed in seawater. Source: F.W. Fink and W.K. Boyd, *The Corrosion of Metals in Marine Environments* (DMIC Report 245), Defense Metals Information Center (Battelle), Columbus, OH, 1970, 14.



LIVE GRAPH
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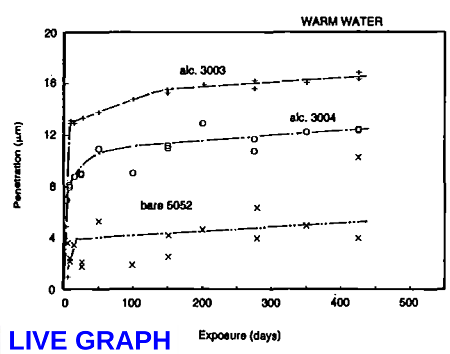
Aluminum alloys. Corrosion data for aluminum alloy samples (3003, 3004, 5052, and 7072 with cladding) exposed in free fouling warm water loops. Source: J. Larsen-Basse, "Performance of OTEC Heat Exchanger Materials in Tropical Seawaters," *Journal of Metals*, Vol 37, Mar 1985, 25.



LIVE GRAPH
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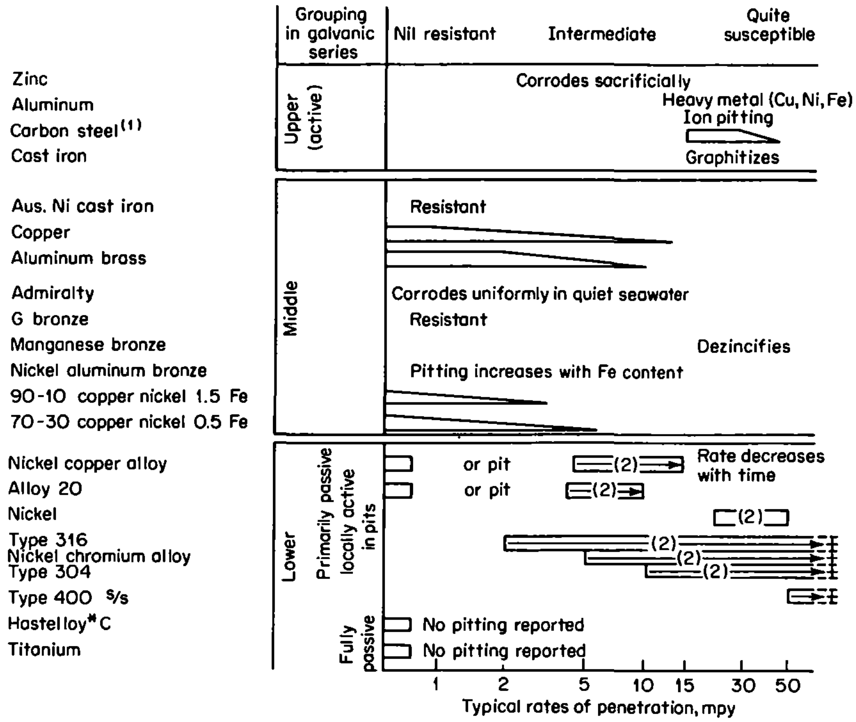
Aluminum alloy. Corrosion data for aluminum alloy samples (3003, 3004, 5052, and 7072 with cladding) exposed in the cold, deep ocean water, calculated as uniform wall loss. Source: J. Larsen-Basse, "Performance of OTEC Heat Exchanger Materials in Tropical Seawaters," *Journal of Metals*, Vol 37, Mar 1985, 26.

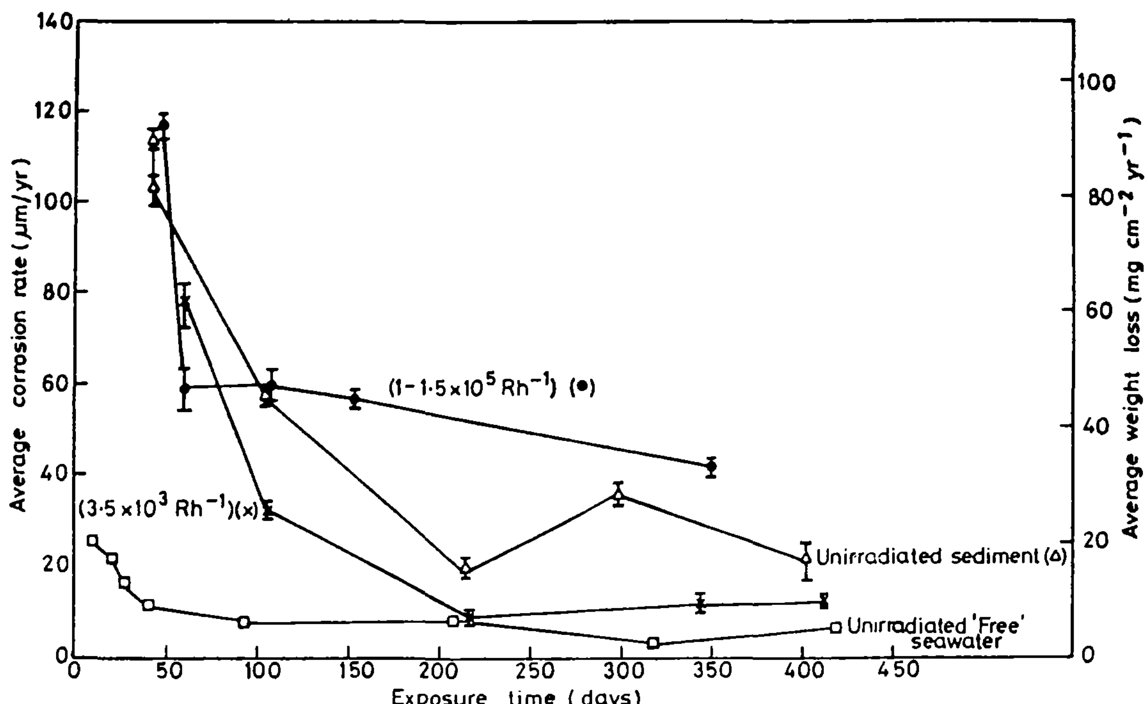


(1) Shallow round-bottom pits

(2) As velocity increases above 3 fps, pitting decreases. When continuously exposed to 5 fps and higher velocities these metals, except series 400 S/s, tend to remain passive without any pitting over the full surface in the absence of crevices.

* Trademark Union Carbide Corporation

Various alloys. Pitting in quiet seawater. Source: M.G. Fontana and N.D. Greene, *Corrosion Engineering*, McGraw-Hill, New York, 1967, 270.



LIVE GRAPH
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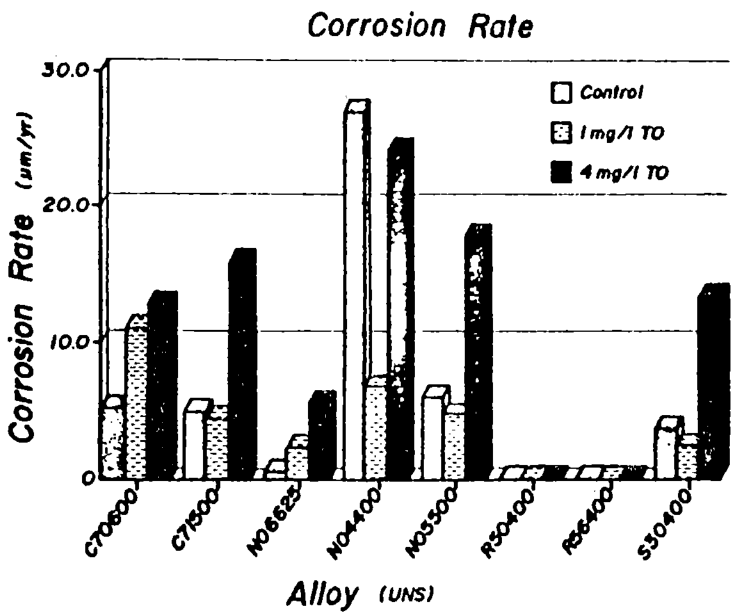
Carbon steel. Average general corrosion rates of forged 0.2% carbon steel in a deaerated synthetic seawater-marine sediment mix at 90 °C (194 °F) with and without λ-radiation (efrror bars indicate one standard deviation from mean). Ref. 260



Control
1 mg/total oxidant (chlorine)
4 mg/total oxidant (chlorine)

C70600 = Cu-Ni 90/10
C71500 = Cu-Ni 70/30
N06625 = Inconel 625
N04400 = Monel 400
N05500 = Monel 500
R50400 = Ti CP2
R56400 = Ti 6-4
S30400 = CRES 304

Various alloys. Corrosion rate for the listed alloys. Ref. 227

Silver Bromide

Silver bromide, AgBr, is pale yellow crystals or powder, that darken on exposure to light, finally turning black and soluble in potassium bromide, potassium cyanide, and sodium thiosulfate solutions, only very slightly soluble in ammonia water, insoluble in water, and light sensitive. Derivation is through silver nitrate dissolving in water and a solution of alkali bromide added slowly. The precipitated silver bromide is washed repeatedly with hot water. The operation must be carried on in a darkroom under a ruby-red light. Used in photographic film and plates, photochromic glass and as a laboratory reagent.

Corrosion Behavior of Various Metals and Alloys in Silver Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Silver Bromide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
430	S43000	...	...	...	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253

Silver Chloride

Silver chloride, AgCl, is a white, granular powder that darkens on exposure to light, finally turning black. It exists in several modifications differing in behavior toward light and solubility in various solvents. Soluble in ammonium hydroxide, concentrated sulfuric acid, and sodium thiosulfate and potassium bromide solutions, very slightly soluble in water; can be melted, cast, and fabricated like a metal. Derived by heating a silver nitrate solution and adding hydrochloric acid or salt solution. The whole is boiled, then filtered. This must take place in the dark or under a ruby-red light. Used in photography, photometry and optics, batteries, photochromic glass, silver plating, production of pure silver, and as an antiseptic. Single crystals are used for infrared absorption cells and lens elements and as a lab reagent.

Corrosion Behavior of Various Metals and Alloys in Silver Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	...	...	Poor	Pitting	253
302	S30200	...	...	...	...	...	Poor	Pitting	253
303	S30300	...	...	...	...	...	Poor	Pitting	253
303	S30300	...	...	...	...	...	Poor	Pitting	253
304	S30400	...	...	...	...	...	Poor	Pitting	253
304L	S30403	...	...	...	...	...	Poor	Pitting	253
304LN	S30453	...	...	...	...	...	Poor	Pitting	253
316	S31600	...	...	...	...	...	Poor	Pitting	253
316F	S31620	...	...	...	...	...	Poor	Pitting	253
316L	S31603	...	...	...	...	...	Poor	Pitting	253
316LN	S31653	...	...	...	...	...	Poor	Pitting	253
316Ti	S31635	...	...	...	...	...	Poor	Pitting	253
317L	S31703	...	...	...	...	...	Poor	Pitting	253
317LN	S31725	...	...	...	...	...	Poor	Pitting	253
321	S32100	...	...	...	...	...	Poor	Pitting	253
329	S32900	...	...	...	...	...	Poor	Pitting	253
347	S34700	...	...	...	...	...	Poor	Pitting	253
430	S43000	...	...	...	...	...	Poor	Pitting	253
F51	S31803	...	...	...	...	...	Poor	Pitting	253

Silver Nitrate

Silver nitrate, $AgNO_3$, is colorless, transparent, tabular, rhombic crystals that become gray or grayish-black on exposure to light in the presence of organic matter. It is odorless with a bitter, caustic, metallic taste. It is caustic, and a strong oxidizing agent that is soluble in cold water, more soluble in hot water, glycerol, and hot alcohol, slightly soluble in ether, and decomposes at boiling point. Used in photographic film, silver plating, silvering mirrors, and as an antiseptic.

Corrosion Behavior of Various Metals and Alloys in Silver Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Fused	10	Boiling	...	Resistant	...	253
301	S30100	...	Fused	10	250 (482)	...	Resistant	...	253
302	S30200	...	Fused	10	Boiling	...	Resistant	...	253
302	S30200	...	Fused	10	250 (482)	...	Resistant	...	253
303	S30300	...	Fused	10	Boiling	...	Resistant	...	253
303	S30300	...	Fused	10	Boiling	...	Resistant	...	253
303	S30300	...	Fused	10	250 (482)	...	Questionable	...	253
303	S30300	...	Fused	10	250 (482)	...	Resistant	...	253
304	S30400	...	Fused	10	Boiling	...	Resistant	...	253
304	S30400	...	Fused	10	250 (482)	...	Resistant	...	253
304L	S30403	...	Fused	10	Boiling	...	Resistant	...	253
304L	S30403	...	Fused	10	250 (482)	...	Resistant	...	253
304LN	S30453	...	Fused	10	Boiling	...	Resistant	...	253
304LN	S30453	...	Fused	10	250 (482)	...	Resistant	...	253
316	S31600	...	Fused	10	Boiling	...	Resistant	...	253
316	S31600	...	Fused	10	250 (482)	...	Resistant	...	253
316F	S31620	...	Fused	10	Boiling	...	Resistant	...	253
316F	S31620	...	Fused	10	250 (482)	...	Resistant	...	253
316L	S31603	...	Fused	10	Boiling	...	Resistant	...	253
316L	S31603	...	Fused	10	250 (482)	...	Resistant	...	253
316LN	S31653	...	Fused	10	Boiling	...	Resistant	...	253
316LN	S31653	...	Fused	10	250 (482)	...	Resistant	...	253
316Ti	S31635	...	Fused	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	Fused	10	250 (482)	...	Resistant	...	253
317L	S31703	...	Fused	10	Boiling	...	Resistant	...	253
317L	S31703	...	Fused	10	250 (482)	...	Resistant	...	253
317LN	S31725	...	Fused	10	Boiling	...	Resistant	...	253
317LN	S31725	...	Fused	10	250 (482)	...	Resistant	...	253
321	S32100	...	Fused	10	Boiling	...	Resistant	...	253
321	S32100	...	Fused	10	250 (482)	...	Resistant	...	253
329	S32900	...	Fused	10	Boiling	...	Resistant	...	253
329	S32900	...	Fused	10	250 (482)	...	Resistant	...	253
347	S34700	...	Fused	10	Boiling	...	Resistant	...	253
347	S34700	...	Fused	10	250 (482)	...	Resistant	...	253
403	S40300	...	Fused	10	Boiling	...	Resistant	...	253
403	S40300	...	Fused	10	250 (482)	...	Poor	...	253
405	S40500	...	Fused	10	Boiling	...	Resistant	...	253
405	S40500	...	Fused	10	250 (482)	...	Poor	...	253
409	S40900	...	Fused	10	Boiling	...	Resistant	...	253

(Continued)

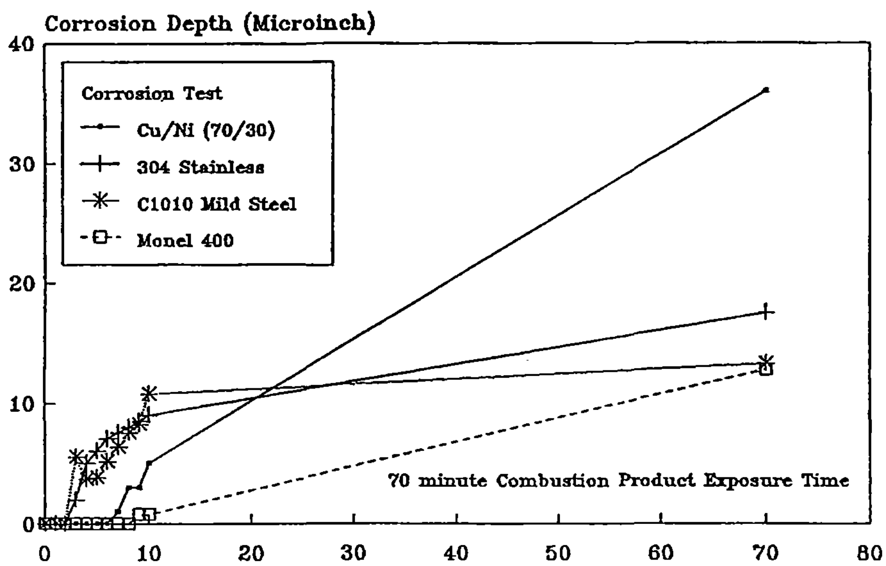
Corrosion Behavior of Various Metals and Alloys in Silver Nitrate (Continued)

Material	UNS	Condition		Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	Fused		10	250 (482)	...	Poor	...	253
410	S41000	...	Fused		10	Boiling	...	Resistant	...	253
410	S41000	...	Fused		10	250 (482)	...	Poor	...	253
416	S41600	...	Fused		10	Boiling	...	Resistant	...	253
416	S41600	...	Fused		10	250 (482)	...	Poor	...	253
420	S42000	...	Fused		10	Boiling	...	Resistant	...	253
420	S42000	...	Fused		10	250 (482)	...	Poor	...	253
430	S43000	...	Fused		10	Boiling	...	Resistant	...	253
430	S43000	...	Fused		10	250 (482)	...	Questionable	...	253
434	S43400	...	Fused		10	Boiling	...	Resistant	...	253
434	S43400	...	Fused		10	250 (482)	...	Resistant	...	253
F51	S31803	...	Fused		10	Boiling	...	Resistant	...	253
F51	S31803	...	Fused		10	250 (482)	...	Resistant	...	253

Smoke and Smog

Smoke. Dispersions of finely divided (0.01 to 5.0 micrometers) solids or liquids in a gaseous medium.

Smog. Air pollution consisting of smoke and fog.



LIVE GRAPH
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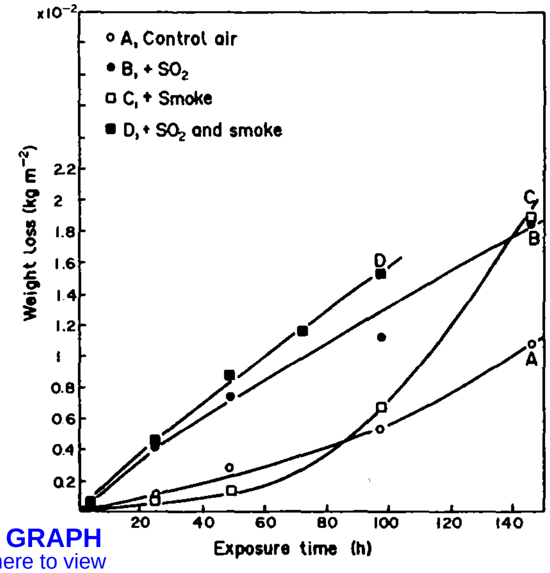
Various alloys. A graph illustrating *in situ* corrosion of the corrosion probe during exposure to the combustion products. Ref. 270



LIVE GRAPH
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Iron foil. Weight loss versus time curves for degreased iron foil in control air, SO_2 and smoke. Ref. 276

Soap

The water-soluble reaction product of a fatty acid ester and an alkali (usually sodium hydroxide), with glycerol as a byproduct. A soap is actually a specific type of salt, the hydrogen of the fatty acid being replaced by a metal, which in common soaps is usually sodium. Soap lowers the surface tension of water and permits emulsification of fat-bearing soil particles. A typical commercial cleaning soap is made by reacting sodium hydroxide with a fatty acid. The lower the hydrogen content of the acid, the thinner is the soap. The byproduct of the reaction is glycerol. Many different carboxyl-containing substances are used, including rosin, tall oil, and vegetable and animal oils and fats (stearic, palmitic, and oleic acids). Olive oil is used for Castile soap and transparent soaps are made from decolorized fats. The specific gravity of soaps is slightly more than 1.0 and the inclusion of air gives a floating product. Water solutions of sodium soaps in bar, chip, or powder form are universally used as mild emulsifying detergents for washing textiles, skin, paint, etc. Medically, soap is used as an antidote for poisoning by ingestion of mineral acids or heavy metals. Liquid green soap is made with potassium hydroxide and a vegetable oil.

Heavy-metal soaps, loosely called metallic soaps, are those formed by metals heavier than sodium (aluminum, calcium, cobalt, lead, and zinc). These soaps are not water-soluble and specific types are used in lubricating greases, gel thickeners, and in paints as dryers and flatting agents. Napalm is an aluminum soap.

Corrosion Behavior of Various Metals and Alloys in Soap

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Soap (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Sodium

Sodium, Na, melts at 97.8 °C and boils at 892 °C. It is silver-white in color, is soft and malleable, and oxidizes in air. It occurs naturally only in the forms of its salts. The most important mineral that contains sodium is sodium chloride (NaCl), or common salt. Sodium is used as a chemical intermediate, and in pharmaceuticals, petroleum refining, and metallurgy. Sodium vapor is used in electric lamps.

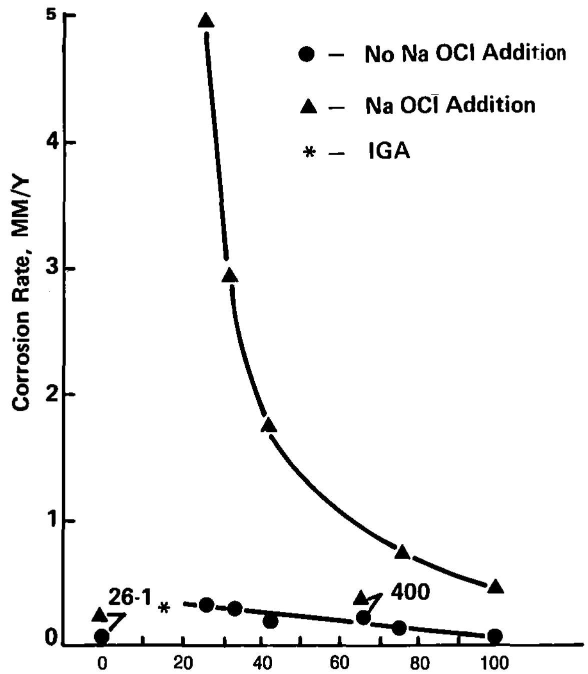
Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy trays have been used for heating sodium in the preparation of sodium products.

Corrosion Behavior of Various Metals and Alloys in Sodium

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Plus K. Dry solid	...	...	...	Resistant	...	92
Refractory metals and alloys									
Titanium	...	...	...	100	Up to 593 (Up to 1100)	...	Good	...	90



Nickel alloys. Effect of nickel content on static corrosion rate of various materials in simulated first-effect plant liquor environments involving quadruple-effect caustic evaporators at 185 °C for 720 h. Source: J.R. Crum and W.G. Lipscomb, "Performance of Nickel 200 and E-Brite 26-1 in First Effect Caustic Environments," *Materials Performance*, Vol 25, Apr, 1986, 10.

Sodium Acetate

Sodium acetate, $NaC_2H_3O_2$, is a colorless, efflorescent crystal, soluble in water and ether. Its melting point is 324 °C.

The anhydrous salt is hygroscopic and forms with water a trihydrate, $CH_3COONa{\cdot}3H_2O$ which loses its water of crystallization completely at 396 K. What is left is the anhydrous salt as a white flaky powder. It dissolves easily in water with temperature reduction and is virtually completely hydrolyzed in water. The solution shows slightly alkaline reaction.

Sodium acetate is prepared by neutralizing acetic acid with sodium hydroxide. The trihydrate crystallizes from the solution below 58 °C. The anhydrous salt is prepared by crystallization above 58 °C and drying in vacuo. The hydrate is used because it is cheaper and dissolves rapidly in water.

Sodium acetate is the most-used alkali metal acetate. The largest amounts are used in medicine as an electrolyte for artificial kidneys and for artificial feeding. It is employed as a buffer substance and corrosion inhibitor. Anhydrous sodium acetate, in organic chemistry, is a mild dehydrating agent and a catalyst, for example in the synthesis of cinnamic acid from benzaldehyde and acetic acid. Other fields of application are in the textile industry (dyeing of wool), the tanneries, food preservation, the photographic industry.

Corrosion Behavior of Various Metals and Alloys in Sodium Acetate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Lead (99.999%)	L50001	...	...	0.8	75 (167)	60 d	.66 (26.0)	...	208
Lead (99.999%)	L50001	...	...	0.08	75 (167)	60 d	.35 (13.8)	...	208

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Acetate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead (99.999%)	L50001	...	...	0.008	75 (167)	60 d	.56 (22.1)	...	208
Lead (99.999%)	L50001	...	...	0.008	75 (167)	60 d	.61 (24.0)	...	208
Stainless steels									
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Resistant	...	253
409	S40900	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Resistant	...	253
420	S42000	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

Sodium Bicarbonate

Sodium bicarbonate, $NaHCO_3$, also known as sodium acid carbonate and baking soda, is a white water-soluble crystalline solid. It has an alkaline taste, loses carbon dioxide at 270 °C (518 °F), and is used in food preparation. Sodium bicarbonate also finds use as a medicine, a butter preservative, in ceramics, and to prevent timber mold.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Iridium. Iridium is slightly attacked by sodium bicarbonate.

Corrosion Behavior of Various Metals and Alloys in Sodium Bicarbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Bicarbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	10	24 (75)	...	0.5 (20) max	...	95
Lead (99.999%)	L50001	...	...	0.05	75 (167)	60 d	.010 (0.4)	...	208
Stainless steels									
301	S30100	...	...	All	20 (68)	...	Resistant	...	253
302	S30200	...	...	All	20 (68)	...	Resistant	...	253
303	S30300	...	...	All	20 (68)	...	Resistant	...	253
303	S30300	...	...	All	20 (68)	...	Resistant	...	253
304	S30400	...	...	All	20 (68)	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Sodium-bicarbonate slurry in solution of ammonium chloride, sodium chloride, and free ammonia 35 titer (carbonating tower)	...	29 (84)	3102 d	0.003 (0.1)	...	89
304	S30400	...	Strong aeration; no agitation. Plus ammonium chloride, remainder sodium chloride, ammonium bicarbonate, hydrogen sulfide, water (liquid); and air, sodium-carbonate dust, ammonia, hydrogen sulfide, water (vapors)	98	28 (82)	36 d	0.003 (0.1) max	...	89
304	S30400	...	Strong aeration; rapid agitation. Slurry saturated with sodium chloride, sodium bicarbonate, ammonium chloride, ammonium bicarbonate, free ammonia and free carbon dioxide (bicarbonating tower)	...	27 (81)	90 d	0.008 (0.3)	Slight pitting	89

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Sodium Bicarbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	All	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	All	20 (68)	...	Resistant	...	253
316	S31600	...	...	All	20 (68)	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Sodium-bicarbonate slurry in solution of ammonium chloride, sodium chloride, and free ammonia 35 titer (carbonating tower)	...	29 (84)	3102 d	0.003 (0.1)	...	89
316	S31600	...	Strong aeration; no agitation. Plus ammonium chloride, remainder sodium chloride, ammonium bicarbonate, hydrogen sulfide, water (liquid); and air, sodium-carbonate dust, ammonia, hydrogen sulfide, water (vapors)	98	28 (82)	36 d	0.003 (0.1) max	...	89
316	S31600	...	Strong aeration; rapid agitation. Plus trace sodium sulfide (carbonating tower), 1% solid ammonium bicarbonate, 1.2% free ammonia, 2% dissolved carbon dioxide, 5% sodium chloride, 15% ammonium chloride, soda-ash draw liquor	20	29 (85)	280 d	0.003 (0.1)	...	89
316	S31600	...	Strong aeration; rapid agitation. Slurry saturated with sodium chloride, sodium bicarbonate, ammonium chloride, ammonium bicarbonate, free ammonia and free carbon dioxide (bicarbonating tower)	...	27 (81)	90 d	0.010 (0.4)	Crevice attack	89
316F	S31620	...	...	All	20 (68)	...	Resistant	...	253
316L	S31603	...	...	All	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	All	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	All	20 (68)	...	Resistant	...	253
317	S31700	...	Strong aeration; rapid agitation. Plus trace sodium sulfide (carbonating tower), 1% solid ammonium bicarbonate, 1.2% free ammonia, 2% dissolved carbon dioxide, 5% sodium chloride, 15% ammonium chloride, soda-ash draw liquor	20	29 (85)	280 d	0.003 (0.1)	...	89
317L	S31703	...	...	All	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	All	20 (68)	...	Resistant	...	253
321	S32100	...	...	All	20 (68)	...	Resistant	...	253
329	S32900	...	...	All	20 (68)	...	Resistant	...	253
347	S34700	...	...	All	20 (68)	...	Resistant	...	253
403	S40300	...	...	All	20 (68)	...	Resistant	...	253
405	S40500	...	...	All	20 (68)	...	Resistant	...	253
409	S40900	...	...	All	20 (68)	...	Resistant	...	253
410	S41000	...	...	All	20 (68)	...	Resistant	...	253

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Sodium Bicarbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	...	All	20 (68)	...	Resistant	...	253
420	S42000	...	...	All	20 (68)	...	Resistant	...	253
430	S43000	...	...	All	20 (68)	...	Resistant	...	253
434	S43400	...	...	All	20 (68)	...	Resistant	...	253
Carpenter 20	...	...	Strong aeration; rapid agitation. Plus trace sodium sulfide (carbonating tower), 1% solid ammonium bicarbonate, 1.2% free ammonia, 2% dissolved carbon dioxide, 5% sodium chloride, 15% ammonium chloride, soda-ash draw liquor	20	29 (85)	280 d	0.003 (0.1)	...	89
F51	S31803	...	...	All	20 (68)	...	Resistant	...	253

Sodium Bisulfate

Also known as sodium acid sulfate, niter cake, sodium hydrogen sulfate, $NaHSO_4$, is colorless crystals or white fused lumps, whose aqueous solution is strongly acid. It is soluble in water and noncombustible. Derived as a byproduct in the manufacture of hydrochloric acid and nitric acid, it is purified by recrystallization. Used as a flux for decomposing minerals, substitute for sulfuric acid in dyeing, disinfectant, in the manufacture of sodium hydrosulfide, sodium sulfate, and soda slum, for liberating CO_2 in carbonic acid baths, in thermophores, for carbonizing wool, in the manufacture of magnesia cements, paper, soap, perfumes, foods, industrial cleaners, metal pickling compounds, and as a lab reagent.

Corrosion Behavior of Various Metals and Alloys in Sodium Bisulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	10	Boiling	...	Good	...	253
302	S30200	...	...	10	Boiling	...	Good	...	253
303	S30300	...	...	10	Boiling	...	Good	...	253
304	S30400	...	...	10	Boiling	...	Good	...	253
304L	S30403	...	...	10	Boiling	...	Good	...	253
304LN	S30453	...	...	10	Boiling	...	Good	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Good	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Bisulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Good	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Good	...	253
434	S43400	...	...	10	Boiling	...	Good	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253

Sodium Bisulfite

Also known as sodium acid sulfite or sodium hydrogen sulfite, $NaHSO_3$ is white crystals or crystalline powder that has a slight sulfurous odor and taste. It is soluble in water, insoluble in alcohol, unstable in air, and non-combustible. Derived by saturating sodium carbonate solution with sulfur dioxide and the solution crystallized. Used as a chemical (sodium salts, cream of tartar), in vat dye preparation, textiles (antichlor, mordant, discharge), food preservative, bleaching groundwood, wool, etc., reducing agent, fermentation, antiseptic, cask sterilization (brewing), copper and brass plating, color preservative for pale crepe rubber, wood pulp digestion, analytical reagent, and as a dietary supplement.

Corrosion Behavior of Various Metals and Alloys in Sodium Bisulfite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Good	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253

Sodium Borate

Sodium borate, $Na_2B_4O_7 \cdot 10H_2O$, also known as sodium tetraborate and sodium pyroborate, is a white crystalline powder that melts at 120 °C (248 °F). Sodium borate in its natural impure form is also known as borax. Sodium borate is used in glass and ceramic enamel mixes, detergents, fertilizers, pharmaceuticals, and photograph.

Corrosion Behavior of Various Metals and Alloys in Sodium Borate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91199	...	Solution	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	...	...	Resistant	...	92
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
301	S30100	...	Molten	...	...	...	Poor	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	Molten	...	...	...	Poor	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	Molten	...	...	...	Poor	...	253
303	S30300	...	Molten	...	...	...	Poor	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	Molten	...	...	...	Poor	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	Molten	...	...	...	Poor	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	Molten	...	...	...	Poor	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	Molten	...	...	...	Poor	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	Molten	...	...	...	Poor	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	Molten	...	...	...	Poor	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	Molten	...	...	...	Poor	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	Molten	...	...	...	Poor	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Borate (Continued)

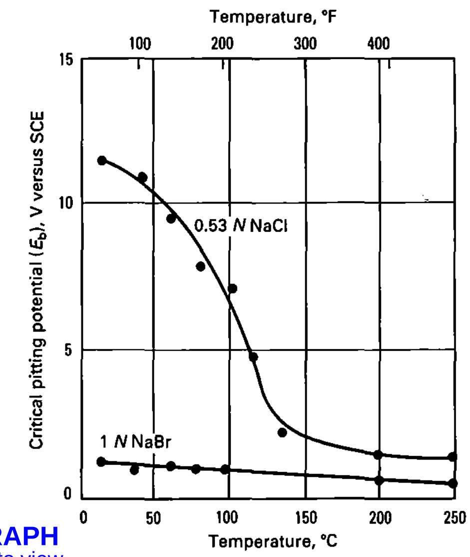
Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	Molten	...	...	...	Poor	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	Molten	...	...	...	Poor	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	Molten	...	...	...	Poor	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	Molten	...	...	...	Poor	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	Molten	...	...	...	Poor	...	253
403	S40300	...	...	Saturated	20 (68)	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	Molten	...	...	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Resistant	...	253
405	S40500	...	...	Saturated	Boiling	...	Resistant	...	253
405	S40500	...	Molten	...	...	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Resistant	...	253
409	S40900	...	...	Saturated	Boiling	...	Resistant	...	253
409	S40900	...	Molten	...	...	...	Poor	...	253
410	S41000	...	...	Saturated	20 (68)	...	Resistant	...	253
410	S41000	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	Molten	...	...	...	Poor	...	253
416	S41600	...	...	Saturated	20 (68)	...	Resistant	...	253
416	S41600	...	...	Saturated	Boiling	...	Resistant	...	253
416	S41600	...	Molten	...	...	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Resistant	...	253
420	S42000	...	...	Saturated	Boiling	...	Resistant	...	253
420	S42000	...	Molten	...	...	...	Poor	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
430	S43000	...	Molten	...	...	...	Poor	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	Molten	...	...	...	Poor	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	Molten	...	...	...	Poor	...	253

Sodium Bromide

Sodium bromide, NaBr, is a white, hygroscopic, crystalline solid with a bitter, saline taste. It is water soluble, with a melting point of 758 °C (1400 °F). Sodium bromide is used in medicine as a sedative and in photography in the preparation of silver bromide emulsion on photographic plates or films.

Corrosion Behavior of Various Metals and Alloys in Sodium Bromide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
7075-T6	A97075	...	...	10.3	22 (72)	14 d	.048 (1.9)	...	257
Miscellaneous									
Magnesium	...	...	...	...	Room	...	Poor	...	119
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	0.23 (9)	...	12
Stainless steels									
410	S41000	...	...	...	Room	...	Good	...	121



LIVE GRAPH
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Titanium. Effect of temperature on the anodic pitting potential of grade 2 titanium in dilute NaCl and NaBr solutions. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 688.

Sodium Carbonate

Sodium carbonate, Na_2CO_3, also known as soda or soda ash, is the most important of the industrial alkalis. It is a white or grayish-white, lumpy, water-soluble powder that loses its water of crystallization when heated. It decomposes at a temperature of about 852 °C (1560 °F).

Soda ash is used in glassmaking, in production of sodium chemicals (such as sodium chromates, phosphates, and silicates), in the wood pulp industry, in production of soaps and detergents, in oil refining, in water softening, and in refining of nonferrous metals. In its hydrous crystallized form ($Na_2CO_3 \cdot 10H_2O$), it is known as sal soda, washing soda, or soda crystals, not to be confused with baking soda, which is sodium hydrogen carbonate or sodium bicarbonate ($NaHCO_3$). Its monohydrate form ($Na_2CO_3 \cdot H_2O$) is the standard compound for scouring solutions.

When in solution, sodium carbonate creates less alkalinity than the hydroxides. A 0.1% solution creates a pH of 11; a fully saturated solution is 35%, which has a pH of 12.5.

The safety requirements for sodium carbonate, because of its lower alkalinity, can be considered less demanding than those for the related bicarbonates.

Sodium carbonate is found in large quantities in a number of states located in the western United States.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given en-

vironment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon Steels. Carbon steels have good resistance to sodium carbonate and are used extensively in sodium carbonate solutions up to boiling temperatures.

Stainless Steels. Stainless steels perform very effectively in sodium carbonate service. Rates of stress-corrosion cracking are similar to those in caustic solutions, but at considerably elevated temperatures.

Aluminum. In laboratory tests conducted at 100% relative humidity and ambient temperature, solid sodium carbonate was very corrosive to aluminum alloy 3003. Other tests showed that aqueous solutions of sodium carbonate (1 to 10%) were corrosive to aluminum alloy 1100. However, this corrosive action was effectively inhibited by the addition of silicates. Sodium carbonate has been transported in aluminum alloy hopper cars.

Zinc. Zinc and zinc brasses are attacked by sodium carbonate, but exhibit beneficial results from various inhibitors.

Corrosion Behavior of Various Metals and Alloys in Sodium Carbonate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Copper-nickel	...	...	...	...	...	...	40 (1.5) max	...	76
Copper-tin	C90700	...	...	...	...	...	50 (2) max	...	76
Copper-zinc	...	...	...	...	...	...	125 (5) max	...	76
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
High purity lead	L50001	...	...	100	8 (46)	...	.02 (0.6)	...	254
Lead	L50045	...	...	...	8 (46)	...	0.015 (0.6)	...	49
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	860 (1580)	...	0.05 (2) max	...	5
Silver	P07010	...	...	...	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	...	0.005	60 (140)	...	0.030 (1.2)	...	75
Tin	...	...	...	0.02	60 (140)	...	0.045 (1.8)	...	75
Tin	...	...	...	0.05	60 (140)	...	0.24 (9.4)	...	75
Tin	...	...	...	0.10	60 (140)	...	0.26 (10.2)	...	75
Tin	...	...	...	0.15	60 (140)	...	0.27 (10.6)	...	75

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Carbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Tin	...	...	...	0.20	60 (140)	...	0.27 (10.6)	...	75
Tin	...	...	...	0.25	60 (140)	...	0.27 (10.6)	...	75
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet	...	...	80 (176)	7 d	Resistant	No pitting	44
Inconel 601	N06601	...	...	10	80 (176)	7 d	Resistant	...	64
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57
Refractory metals and alloys									
Niobium	R04210	...	...	10	Room	...	0.025 (1.0)	...	2
Titanium	...	...	...	20	Boiling	...	Resistant	...	1
Titanium	...	...	...	20	Boiling	...	Resistant	...	1
Titanium	...	...	...	25	Boiling	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	10% saturated	Boiling	...	Resistant	...	253
301	S30100	...	Fused	...	Boiling	...	Resistant	...	253
301	S30100	...	Fused	...	900 (1652)	...	Poor	...	253
302	S30200	...	...	10% saturated	Boiling	...	Resistant	...	253
302	S30200	...	Fused	...	Boiling	...	Resistant	...	253
302	S30200	...	Fused	...	900 (1652)	...	Poor	...	253
303	S30300	...	...	10% saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	10% saturated	Boiling	...	Resistant	...	253
303	S30300	...	Fused	...	Boiling	...	Resistant	...	253
303	S30300	...	Fused	...	Boiling	...	Resistant	...	253
303	S30300	...	Fused	...	900 (1652)	...	Poor	...	253
303	S30300	...	Fused	...	900 (1652)	...	Poor	...	253
304	S30400	...	...	10% saturated	Boiling	...	Resistant	...	253
304	S30400	...	Chemical processing; field or pilot plant test; strong aeration; rapid agitation. Plus 8% sodium chloride, 8% sodium borate, and 2.5% sodium sulfate	25.4	66 (150)	60 d	0.4 (16)	Severe pitting	89
304	S30400	...	Fused	...	Boiling	...	Resistant	...	253
304	S30400	...	Fused	...	900 (1652)	...	Poor	...	253
304L	S30403	...	...	10% saturated	Boiling	...	Resistant	...	253
304L	S30403	...	Fused	...	Boiling	...	Resistant	...	253
304L	S30403	...	Fused	...	900 (1652)	...	Poor	...	253
304LN	S30453	...	...	10% saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	Fused	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Fused	...	900 (1652)	...	Poor	...	253
316	S31600	...	...	10% saturated	Boiling	...	Resistant	...	253
316	S31600	...	Fused	...	Boiling	...	Resistant	...	253
316	S31600	...	Fused	...	900 (1652)	...	Poor	...	253
316F	S31620	...	...	10% saturated	Boiling	...	Resistant	...	253
316F	S31620	...	Fused	...	Boiling	...	Resistant	...	253
316F	S31620	...	Fused	...	900 (1652)	...	Poor	...	253
316L	S31603	...	...	10% saturated	Boiling	...	Resistant	...	253
316L	S31603	...	Fused	...	Boiling	...	Resistant	...	253
316L	S31603	...	Fused	...	900 (1652)	...	Poor	...	253
316LN	S31653	...	...	10% saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	Fused	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Carbonate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	Fused	...	900 (1652)	...	Poor	...	253
316Ti	S31635	...	...	10% saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	Fused	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Fused	...	900 (1652)	...	Poor	...	253
317L	S31703	...	...	10% saturated	Boiling	...	Resistant	...	253
317L	S31703	...	Fused	...	Boiling	...	Resistant	...	253
317L	S31703	...	Fused	...	900 (1652)	...	Poor	...	253
317LN	S31725	...	...	10% saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	Fused	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Fused	...	900 (1652)	...	Poor	...	253
321	S32100	...	...	10% saturated	Boiling	...	Resistant	...	253
321	S32100	...	Fused	...	Boiling	...	Resistant	...	253
321	S32100	...	Fused	...	900 (1652)	...	Poor	...	253
329	S32900	...	...	10% saturated	Boiling	...	Resistant	...	253
329	S32900	...	Fused	...	Boiling	...	Resistant	...	253
329	S32900	...	Fused	...	900 (1652)	...	Poor	...	253
347	S34700	...	...	10% saturated	Boiling	...	Resistant	...	253
347	S34700	...	Fused	...	Boiling	...	Resistant	...	253
347	S34700	...	Fused	...	900 (1652)	...	Poor	...	253
403	S40300	...	...	10% saturated	Boiling	...	Resistant	...	253
403	S40300	...	Fused	...	Boiling	...	Resistant	...	253
403	S40300	...	Fused	...	900 (1652)	...	Poor	...	253
405	S40500	...	...	10% saturated	Boiling	...	Resistant	...	253
405	S40500	...	Fused	...	Boiling	...	Resistant	...	253
405	S40500	...	Fused	...	900 (1652)	...	Poor	...	253
409	S40900	...	...	10% saturated	Boiling	...	Resistant	...	253
409	S40900	...	Fused	...	Boiling	...	Resistant	...	253
409	S40900	...	Fused	...	900 (1652)	...	Poor	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	10	0-93 (0-200)	...	Resistant	...	121
410	S41000	...	...	50	0-93 (0-200)	...	Resistant	...	121
410	S41000	...	...	10% saturated	Boiling	...	Resistant	...	253
410	S41000	...	Fused	...	Boiling	...	Resistant	...	253
410	S41000	...	Fused	...	900 (1652)	...	Poor	...	253
416	S41600	...	...	10% saturated	Boiling	...	Resistant	...	253
416	S41600	...	Fused	...	Boiling	...	Resistant	...	253
416	S41600	...	Fused	...	900 (1652)	...	Poor	...	253
420	S42000	...	...	10% saturated	Boiling	...	Resistant	...	253
420	S42000	...	Fused	...	Boiling	...	Resistant	...	253
420	S42000	...	Fused	...	900 (1652)	...	Poor	...	253
430	S43000	...	...	10% saturated	Boiling	...	Resistant	...	253
430	S43000	...	Fused	...	Boiling	...	Resistant	...	253
430	S43000	...	Fused	...	900 (1652)	...	Poor	...	253
434	S43400	...	...	10% saturated	Boiling	...	Resistant	...	253
434	S43400	...	Fused	...	Boiling	...	Resistant	...	253
434	S43400	...	Fused	...	900 (1652)	...	Poor	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	10% saturated	Boiling	...	Resistant	...	253
F51	S31803	...	Fused	...	Boiling	...	Resistant	...	253
F51	S31803	...	Fused	...	900 (1652)	...	Poor	...	253

Sodium Chlorate

Sodium chlorate, $NaClO_3$, is colorless, odorless crystals with a cooling, saline taste, is soluble in water and alcohol, but must not be triturated with any combustible substance. Derived by heating and electrolyzing a concentrated acid solution of sodium chloride so that the chlorate is crystallized out. Used as an oxidizing agent and bleach (especially to make chlorine dioxide) for paper pulps, ore processing, herbicide and defoliant, substitute for potassium chlorate (sodium chlorate is more soluble in water), matches, explosives, flares, and pyrotechnics, in the recovery of bromine from natural brines, leather tanning and finishing, textile mordant, and to make perchlorates.

Corrosion Behavior of Various Metals and Alloys in Sodium Chlorate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	30	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	30	Boiling	...	Resistant	Pitting	253
302	S30200	...	...	30	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	30	Boiling	...	Resistant	Pitting	253
303	S30300	...	...	30	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	30	Boiling	...	Resistant	Pitting	253
304	S30400	...	...	30	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	30	Boiling	...	Resistant	Pitting	253
304L	S30403	...	...	30	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	30	Boiling	...	Resistant	Pitting	253
304LN	S30453	...	...	30	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	30	Boiling	...	Resistant	Pitting	253
316	S31600	...	...	30	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	30	Boiling	...	Resistant	Pitting	253
316F	S31620	...	...	30	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	30	Boiling	...	Resistant	Pitting	253
316L	S31603	...	...	30	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	30	Boiling	...	Resistant	Pitting	253
316LN	S31653	...	...	30	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	30	Boiling	...	Resistant	Pitting	253
316Ti	S31635	...	...	30	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	30	Boiling	...	Resistant	Pitting	253
317L	S31703	...	...	30	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	30	Boiling	...	Resistant	Pitting	253
317LN	S31725	...	...	30	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	30	Boiling	...	Resistant	Pitting	253
321	S32100	...	...	30	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	30	Boiling	...	Resistant	Pitting	253
329	S32900	...	...	30	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	30	Boiling	...	Resistant	Pitting	253
347	S34700	...	...	30	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	30	Boiling	...	Resistant	Pitting	253
F51	S31803	...	...	30	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	30	Boiling	...	Resistant	Pitting	253

Sodium Chloride

Sodium chloride, NaCl, also known as common salt and halite, is a white crystalline solid. It is soluble in water, slightly soluble in alcohol, and melts at 804 °C (1480 °F). Sodium chloride is the most important sodium mineral and occurs naturally in seawater, underground deposits, and brine wells. Sodium chloride is a basic raw material for the production of chlorine, sodium hypochlorite, sodium bisulfate, soda ash, and hydrogen chloride. Sodium chloride is also used in food preparation, fertilizers, and by highway departments to control icy road conditions.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloys are used to ship, store, and handle sodium chloride either as a solid, as an aqueous solution, or as a brine in refrigeration systems. Sodium chloride is a standard testing medium to determine the corrosion and stress-corrosion cracking resistance of aluminum alloys. Aqueous solutions of 0.1 to 25% sodium chloride mildly attacked (0.05 mm/yr, or 2 mils/yr) alloy 1100 and produced localized pitting in tests run at ambient temperature. The presence of heavy metals in the solutions will increase the corrosion attack.

Amorphous Metals. Amorphous metals showed a sharp decrease in corrosion rate with increased chromium content and no sign of pitting in a 1*N* sodium chloride solution. Stress-corrosion cracking of a $Ni_{49}Fe_{29}P_{14}B_6Al_2$ glassy alloy was observed in a 3.5*N* sodium chloride solution, although one researcher suggested that the fracture was hydrogen induced.

Copper. Sodium chloride solutions reduce the service life of copper alloys under cyclic stress. Aluminum bronzes are generally suitable for service in sodium chloride.

Nickel. Nickel alloys have good resistance to solid sodium chloride.

Titanium. Titanium alloys are susceptible to crevice corrosion in hot, low pH, concentrated sodium chloride solutions. Crevice corrosion does not generally occur at temperatures below 70 °C (160 °F) or at pH values above 10. Grade 12 provides the greatest crevice corrosion resistance in solutions with pH values of 3 to 11 with temperatures as high as 300 °C (570 °F). Titanium alloys containing at least 4 wt% molybdenum (Ti-3-8-6-4-4 alloy) revealed no crevice corrosion in low pH, high-temperature tests. The addition of dissolved oxidizing species and imposing an anodic potential can reduce attack time and increase the attack rate of sodium chloride solutions on titanium alloys.

Zirconium. Zirconium resists stress-corrosion cracking in sodium chloride.

Powder/Metallurgy Alloys. Aluminum-magnesium alloys IN-9052 and IN-9021 were tested by alternate immersion in a sodium chloride solution (ASTM G 44). IN-9052 had a corrosion rate two magnitudes lower than that of the conventional 7075-T73. Another study involving short-term exposure in a 3.5% sodium chloride solution showed IN-9021 to be very susceptible to pitting, with a corrosion rate three times greater than that of the conventional 7075 alloy.

Low-Alloy Steel. Low-alloy sintered steel exhibited poor corrosion resistance to a 3% sodium chloride solution at high and low oxidation temperatures.

Sintered Stainless Steels. The corrosion resistance of sintered stainless steels in a chloride environment depends on the iron contamination and on the carbon, nitrogen, oxygen, and sintered part density.

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
2024-T3	A92024	...	...	3.5	25	...	.32 (12.9)	...	231
2014-T5	A92014	...	pH 6	3.5	22 (72)	7 d	.068 (2.7)	...	247
2014-T5	A92014	...	pH 6	8.5	22 (72)	7 d	.070 (2.8)	...	247
2091-T8	A92091	...	pH 6	3.5	22 (72)	7 d	.15 (5.9)	...	247
2091-T8	A92091	...	pH 6	8.5	22 (72)	7 d	.065 (2.6)	...	247
2091-T8	A92091	...	pH 6	8.5	22 (72)	7 d	...	...	247
5052-H34	A95052	...	...	3.5	25	...	.11 (4.5)	...	231
7075-T6	A97075	...	...	5.8	22 (72)	14 d	.042 (1.7)	...	257
7075-T6	A97075	...	...	3.5	25	...	.31 (12.5)	...	231
7075-T73	A97075	...	...	3.5	25	...	.40 (16.0)	...	231
8090-T5	A98090	...	pH 6	8.5	22 (72)	7 d	.055 (2.2)	...	247
8090-T6	A98090	...	pH 6	3.5	22 (72)	7 d	.090 (3.5)	...	247

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
8090-T81	A98090	...	pH 1	3.5	27	...	21 (840)	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 1	3.5	27	...	7 (280)	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 10	3.5	27	...	1 (40) max	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 10	3.5	27	...	1 (40) max	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 11	3.5	27	...	4 (160)	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 11	3.5	27	...	3 (120)	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 2	3.5	27	...	1 (40) max	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 2	3.5	27	...	1 (40) max	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 6	3.5	27	...	1 (40) max	...	194
Aluminum (99.0-99.5%)	A91199	...	pH 6	3.5	27	...	1 (40) max	...	194
IN-9021-T452	...	...	Aerated	3.5	20 (68)	3 d	0.23 (8.9)	...	168
IN-9021-T452	...	...	Aerated	3.5	20 (68)	7 d	0.58 (23.1)	...	168
IN-9021-T452	...	...	Aerated	3.5	20 (68)	14 d	0.27 (10.9)	...	168
IN-9021-T452	...	...	Aerated	3.5	20 (68)	28 d	0.22 (8.8)	...	168
Carbon and alloy steel									
1020 steel	G10200	...	pH 2.0, 100 ppm acetic acid + HCI	3.5	22-25	48 h	...	Maximum Pittin g .016 (.64)	198
1020 steel	G10200	...	pH 2.0, 100 ppm chloroacetic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .04 (1.6)	198
1020 steel	G10200	...	pH 2.0, 100 ppm formic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .020 (.8)	198
1020 steel	G10200	...	pH 2.0, 1000 ppm acetic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .002 (.08)	198
1020 steel	G10200	...	pH 2.0, 1000 ppm chloroacetic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .01 (0.4)	198
1020 steel	G10200	...	pH 2.0, 1000 ppm formic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	Resistant	...	198
1020 steel	G10200	...	pH 2.0, 500 ppm acetic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .006 (.24)	198
1020 steel	G10200	...	pH 2.0, 500 ppm chloroacetic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .04 (1.6)	198
1020 steel	G10200	...	pH 2.0, 500 ppm formic acid + HCI, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .004 (.16)	198
1020 steel	G10200	...	pH 2.1, 1000 ppm chloroacetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .014 (.56)	198
1020 steel	G10200	...	pH 2.3, 500 ppm chloroacetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .014 (.56)	198
1020 steel	G10200	...	pH 2.5, 1000 ppm formic acid, CO_2 saturated solution	3.5	22-25	48 h	Resistant	...	198
1020 steel	G10200	...	pH 2.7, 500 ppm formic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .016 (.64)	198
1020 steel	G10200	...	pH 2.8, 100 ppm chloroacetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .020 (.08)	198

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
1020 steel	G10200	...	pH 3.0, 1000 ppm acetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .001 (0.4)	198
1020 steel	G10200	...	pH 3.1, 100 ppm formic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .036 (1.4)	198
1020 steel	G10200	...	pH 3.3, 500 ppm acetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .002 (0.8)	198
1020 steel	G10200	...	pH 3.5, 100 ppm acetic acid, CO_2 saturated solution	3.5	22-25	48 h	...	Maximum pitting .01 (0.4)	198
4130 steel	G41300	...	Sour well production fluid in equilibrium with 1 psi H_2S and 1200 psi CO_2	25	200	30 d	.29 (11.7)	Pitting	207
4130 steel	G41300	...	Sweet well production fluid, in equilibrium with 1200 psi CO_2	5	150	30 d	.09 (3.5)	Crevice attack	207
4340 steel	G43400	...	...	3.5	25	...	.55 (21.8)	...	231
9 Cr steel	S50400	...	Packer fluid, deaerated brine. 400 psi CO_2	5	150	30 d	.19 (7.5)	Crevice attack	207
9 Cr steel	S50400	...	Sour well production fluid in equilibrium with 1 psi H_2S and 1200 psi CO_2	25	200	30 d	.31 (12.3)	...	207
Copper and alloys									
70-30 cuproNickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cuproNickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Iron and alloys									
Ductile iron (1.5%Ni)	...	...	As-cast with pearlitic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.73 (29)	...	167
Ductile iron (1.5%Ni)	...	...	As-cast with pearlitic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.78 (31)	...	167
Gray cast iron (1.5%Ni)	...	...	Annealed with ferritic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.65 (26)	...	167
Gray cast iron (1.5%Ni)	...	...	As-cast with pearlitic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.68 (27)	...	167

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Unalloyed gray cast iron	...	...	Annealed with ferritic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.70 (28)	...	167
Unalloyed gray cast iron	...	...	As-cast with pearlitic matrix. Air saturated; specimens moved at 16 ft/min for 7 d	3.5	30 (86)	...	0.90 (36)	...	167
Lead and alloys									
Lead (99.999%)	L50001	...	...	2.9	75 (167)	60 d	.005 (0.2)	...	208
Lead (99.999%)	L50001	...	...	0.3	75 (167)	60 d	.008 (0.3)	...	208
Lead (99.999%)	L50001	...	...	0.03	75 (167)	60 d	.024 (0.9)	...	208
Lead (99.999%)	L50001	...	...	0.003	75 (167)	60 d	.434 (17.1)	...	208
Lead (99.999%)	L50001	...	...	0.3	70 (68)	60 d	.005 (.002)	...	208
Miscellaneous									
A291	M11910	F temp	Mold preheated at 250°C	5	23	3 d	4.0 (160)	...	236
A291	M11910	T4 temp	Mold preheated at 250°C	5	23	3 d	5.4 (216)	...	236
A291	M11910	T6 temp	Mold preheated at 250°C	5	23	3 d	0.8 (32)	...	236
A291	M11910	F temp	Mold preheated at 350°C	5	23	3 d	2.8 (112)	...	236
A291	M11910	T4 temp	Mold preheated at 350°C	5	23	3 d	3.6 (144)	...	236
A291	M11910	T6 temp	Mold preheated at 350°C	5	23	3 d	0.8 (32)	...	236
A291	M11910	F temp	Mold preheated at 400°C	5	23	3 d	2.2 (88)	...	236
A291	M11910	T4 temp	Mold preheated at 400°C	5	23	3 d	7.2 (288)	...	236
A291	M11910	T6 temp	Mold preheated at 400°C	5	23	3 d	1.0 (40)	...	236
AZ31B	...	...	Alternate immersion 14 d	3	...	14 d	0.6 (24)	...	170
AZ61A	M11610	Strain hardened and partially annealed; sheet	Alternate immersion 14 d	3	...	14 d	0.4 (16)	...	170
AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	0.3 (11)	...	12
AZ63A	M11630	Sand casting	Alternate immersion 14 d	3	...	14 d	3 (120)	...	170
AZ63A	M11630	Solution heat treated; sand casting	Alternate immersion 14 d	3	...	14 d	8 (320)	...	170
AZ63A	M11630	Solution heat treated and artificially aged; sand casting	Alternate immersion 14 d	3	...	14 d	4 (160)	...	170
AZ92A	M11920	Sand casting	Alternate immersion 14 d	3	...	14 d	8 (320)	...	170
AZ92A	M11920	Solution heat treated; sand casting	Alternate immersion 14 d	3	...	14 d	20 (800)	...	170
AZ92A	M11920	Solution heat treated and artificially aged; sand casting	Alternate immersion 14 d	3	...	14 d	12 (480)	...	170
HK31A	M13310	Strain hardened, artificially annealed; sheet	Alternate immersion 14 d	3	...	14 d	0.4 (16)	...	170
HM21A	M13210	Solution heat treated, strain hardened, and artificially aged; sheet	Alternate immersion 14 d	3	...	14 d	0.4 (16)	...	170
Lead	L50045	...	...	0.25-6	8 (46)	...	0.03 (1.2) max	...	49
Lead	L50045	...	...	0.5-24	25 (77)	...	0.05 (2) max	...	95
M1A	...	Extrusion	Alternate immersion 14 d	3	...	14 d	0.8 (32)	...	170
Magnesium	...	...	...	All	Room	...	Poor	...	119
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Platinum	P04995	...	Melt	...	800 (1470)	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Zinc	Z13001	...	Plus 10 ppm $CeCl_3$	0.1m	22-25	500 h	.15 (6.1)	...	205
Zinc	Z13001	...	Plus 10,000 ppm $CeCl_3$	0.1m	22-25	500 h	.31 (12.2)	...	205
Zinc	Z13001	...	Plus 100 ppm $CeCl_3$	0.1m	22-25	500 h	.15 (6.0)	...	205
Zinc	Z13001	...	Plus 1000 ppm $CeCl_3$	0.1m	22-25	500 h	.22 (8.8)	...	205
ZK60A	...	Artificially aged; extrusion	Alternate immersion 14 d	3	...	14 d	1.6 (64)	...	170
Nickel and alloys									
718	N07718	...	Sour well production fluid in equilibrium with 1 psi H_2S and 1200 psi CO_2	25	200	30 d	.005 (0.2)	...	207
718	N07718	...	Sweet well production fluid, in equilibrium with 1200 psi CO_2	5	150	30 d	.003 (0.1) max	...	207
Allcorr	N06110	...	Plus 5% ferric chloride	10	104 (219)	...	.076	Severe crevice attack	220
Allcorr	N06110	...	Plus 5% ferric chloride	10	70 (158)	...	.005	Severe crevice attack	220
Allcorr	N06110	...	Plus 5% ferric chloride	10	30 (86)	...	.041	Moderate crevice attack	220
Alloy 625	N06625	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235
Alloy 625	N06625	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.1) max	...	235
Alloy 625	N06625	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Alloy 625	N06625	...	Plus 5% ferric chloride	10	104 (219)	...	56	Severe pit and crevice attack	220
Alloy 625	N06625	...	Plus 5% ferric chloride	10	70 (158)	...	16	Severe pit and crevice attack	220
Alloy 625	N06625	...	Plus 5% ferric chloride	10	30 (86)	...	76	Severe crevice attack	220
Alloy 825	N08825	...	Brine production; strong aeration; slight to moderate agitation. Sodium chloride brine, with 18 g/L sodium sulfate, 18 g/L sodium carbonate and 1 g/L sodium hydroxide	~23.5	Room to 71 (160)	225 d	Resistant	...	89
Alloy 825	N08825	...	Labortory test; slight to moderate aeration; slight to moderate agitation. Plus 240 g/L ammonium perchlorate, 78 g/L sodium perchlorate, 2 g/L sodium chlorate, trace ammonium chloride and pH 4.8	~15.3	68-77 (155-170)	98 d	0.003 (0.1)	Slight pitting	89
Alloy 825	N08825	...	No aeration; rapid agitation. Plus 1% sodium hydroxide	5-4	104 (220)	58 d	0.003 (0.1) max	Crevice attack	89
Alloy 825	N08825	...	No agitation. Acidic salt stripping solution with 70 g/L chloride, 50 g/L sulfate, 20-25 g/L nitrate, 4-5 g/L thorium, 1 g/L ferric ion, sulfuric acid 0.1*N*, and pH approx. 0.5	10.5	31 (86)	21 d	0.15 (6)	Severe pitting; crevice attack	89
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.2)	Pitted	235
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.2)	Pitted	235
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Alloy 825	N08825	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Alloy 825	N08825	...	Slight to moderate aeration; slight to moderate agitation. Saturated sodium chloride brine	...	71 (160)	204 d	0.003 (0.1) max	Crevice attack	89
Alloy 825	N08825	...	Slight to moderate aeration; slight to moderate agitation. Sodium chloride solution saturated to 15.3% (alternate immersion)	...	16-27 (60-80)	160 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Soap processing;no aeration; no agitation. Saturated salt solution of glycerine and water, with 1-80% glycerine (Wooster-Sanger evaporator, vapors)	...	60-104 (140-220)	91 d	0.003 (0.1) max	Crevice attack	89
Alloy 825	N08825	...	Strong aeration; rapid agitation. Oil-field brine, 10% calcium and magnesium chlorides, 0.4% bromine, pH 6	0.15	65 (149)	144 d	0.3 (12)	Severe pitting	89
Alloy C-22	N06022	...	Plus 5% ferric chloride	10	104 (219)	...	.025	Severe crevice attack	220
Alloy C-22	N06022	...	Plus 5% ferric chloride	10	70 (158)	...	.005	Severe crevice attack	220
Alloy C-22	N06022	...	Plus 5% ferric chloride	10	30 (86)	...	.013	Severe crevice attack	220
Alloy C-276	N10276	...	Plus 5% ferric chloride	10	104 (219)	...	.076	Severe crevice attack	220
Alloy C-276	N10276	...	Plus 5% ferric chloride	10	70 (158)	...	.003	Severe crevice attack	220
Alloy C-276	N10276	...	Plus 5% ferric chloride	10	30 (86)	...	.061	Severe crevice attack	220
Alloy G-2	N06975	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235
Alloy G-2	N06975	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.1) max	...	235
Alloy G-2	N06975	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Cabot alloy No.625	N06625	...	...	4	Room	24 h	Resistant	...	67
Cabot alloy No.625	N06625	...	...	4	70 (158)	24 h	Resistant	...	67
Cabot alloy No.625	N06625	...	...	4	Boiling	24 h	Resistant	...	67
Cabot alloy No.625	N06625	...	With cervice	3	Room	96 h	Resistant	...	67
Cabot alloy No.625	N06625	...	With cervice	3	50 (122)	96 h	Resistant	...	67
Cabot alloy No.625	N06625	...	With cervice	3	70 (158)	96 h	Resistant	...	67
Inco Alloy G	N06007	...	35,000 ppm chloride as NaCl (pH 5.0) simulated SO_2 scrubber environment. 26% of crevice area attacked	...	58 (135)	30 d	0.025 (1) max	Maximum crevice depth <0.05 mm (<2 mils)	40
Inco alloy G-3	N06985	...	35,000 ppm chloride as NaCl (pH 5.0) simulated SO_2 scrubber environment. 33% of crevice area attacked	...	58 (135)	30 d	0.025 (1) max	Maximum crevice depth <0.05 mm (<2 mils)	40
Incoloy 800	N08800	Cold-rolled, annealed sheet	...	10	80 (176)	42 d	0.003 (0.1) max	Incipient pits	44
Incoloy 800	N08800	Cold-rolled annealed sheet	...	20	80 (176)	42 d	0.008 (0.3)	Pitting occurred after 7 d	44

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Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Incoloy alloy 800H	N08810	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.2)	...	235
Incoloy alloy 800H	N08810	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.4)	...	235
Incoloy alloy 800H	N08810	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.6)	...	235
Inconel 601	N06601	...	...	10	80 (176)	30 d	0.005 (0.2)	Pitting attack	64
Inconel 601	N06601	...	...	20	80 (176)	30 d	0.008 (0.3)	Pitting attack	64
Refractory metals and alloys									
B/C Titanium and alloys	R58640	...	Sour well production fluid in equilibrium with 1 psi H_2S and 1200 psi CO_2	25	200	30 d	.003 (0.1)	...	207
B/C Titanium and alloys	R58640	...	Sweet well production fluid, in equilibrium with 1200 psi CO_2	5	150	30 d	.003 (0.1) max	...	207
Hafnium	...	...	pH 1	Saturated	...	21 d	0.03 (1) max	...	11
Hafnium	...	...	Saturated solution pH 1	Saturated	...	21 d	0.03 (1) max	...	11
Niobium	R04210	...	Saturated solution pH 1	Saturated	Boiling	...	0.03 (1.0) max	...	2
Ti-3Al-2.5V, grade 9	...	...	Plus 0.5% CH_3COOH + 0.1% S + saturated H_2S	25	Room	...	Resistant	...	91
Ti-3Al-2.5V, grade 9	...	...	Plus 0.5% CH_3COOH + saturated H_2S.	5	Room	...	Resistant	...	91
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Titanium	...	...	pH 1.2	23	Boiling	...	0.71 (28.4)	...	90
Titanium	...	...	pH 1.2; some dissolved Cl_2	23	Boiling	...	Resistant	...	90
Titanium	...	...	pH 1.5	23	Boiling	...	Resistant	...	90
Titanium	...	...	pH 7	23	Boiling	...	Resistant	...	90
Titanium	...	...	Plus 0.5% CH_3COOH + 0.1% S + saturated H_2S	25	Room	...	Resistant	...	91
Titanium	...	...	Plus 0.5% CH_3COOH + saturated H_2S	5	Room	...	Resistant	...	91
Titanium, grade 12	R53400	...	Plus chlorine, Tight crevices pH 1.2.	Saturated	Boiling	...	Poor	...	215
Titanium, grade 12	R53400	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Plus chlorine, Tight crevices pH 1.2	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Plus chlorine, Tight crevices pH 1.2.	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235
Titanium, grade 2	R50400	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.1)	...	235
Titanium, grade 2	R50400	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Titanium, grade 2	R50400	...	Plus chlorine, Tight crevices pH 1.2	Saturated	Boiling	...	Poor	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 3	Saturated	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	Plus chlorine, Tight crevices pH 1.2	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 7	R52400	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 9	...	...	pH 1	Saturated	93 (200)	...	Resistant	...	33
Zr702	R60702	...	...	3 to saturated	35 to boiling (95 to boiling)	...	0.025 (1) max	...	15
Zr702	R60702	...	...	29	Boiling	...	0.025 (1) max	...	15
Zr702	R60702	...	...	Saturated	Room	...	0.025 (1) max	...	15
Zr702	R60702	...	Adjusted to pH 0	Saturated	107 (225)	...	Resistant	...	15
Zr702	R60702	...	Adjusted to pH 1	Saturated	Boiling	...	0.025 (1) max	...	15

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Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zr702	R60702	...	Plus 0.5% acetic acid, 1% S, saturated H_2S	25	215 (420)	...	Resistant	...	15
Zr702	R60702	...	Plus saturated SO_2	3.5	80 (175)	...	Resistant	...	15
Zr702	R60702	...	Plus saturated SO_2	25	80 (175)	...	Resistant	...	15
Zr702	R60702	...	Plus saturated SO_2	Saturated	80 (175)	...	Resistant	...	15
Zr702	R60702	...	Saturated concentration, adjusted to pH 1	Saturated	Boiling	...	0.025 (1.0)	...	62
Zr704	R60704	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2	5	(75-150)	...	(0.1) max	...	235
Zr704	R60704	Tube liner	Plus 0.5% acetic acid and 100 psi H_2S	...	(400)	...	(0.1) max	...	235
Zr704	R60704	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(0.1) max	...	235
Zr704	R60704	...	Plus 0.5% acetic acid, 1% S, saturated H_2S	25	215 (420)	...	Resistant	...	15
Zr705	R60705	...	...	3 to saturated	35 to boiling (95 to boiling)	...	0.025 (1) max	...	15
Zr705	R60705	...	Adjusted to pH 1	Saturated	Boiling	...	0.025 (1) max	...	15
Zr705	R60705	...	Plus 0.5% acetic acid, 1% S, saturated H_2S	25	215 (420)	...	Resistant	...	15
Zr705	R60705	...	Saturated concentration, adjusted to pH 1	Saturated	Boiling	...	0.025 (1)	...	62
Stainless steels									
13Cr steel	S41000	...	16Ni, 8Cr, 5Si, 1Cu	5	150	30 d	44 (17.7)	...	207
13Cr steel	S41000	...	16Ni, 8Cr, 5Si, 1Cu, 1Mo	25	200	30 d	.32 (12.9)	Pitting	207
21Cr-9Ni-3Mo-N,V	...	...	With 0.1 atm, H_2S, 10 atn CO_2	...	100	14 d	...	No pitting	237
21Cr-9Ni-3Mo-N,V	...	...	With 0.1 atm, H_2S, 10 atn CO_2	...	120	14 d	...	No pitting	237
21Cr-9Ni-3Mo-N,V	...	...	With 0.1 atm, H_2S, 10 atn CO_2	...	150	14 d	...	Pitting 0.24 (10)	237
2205	S31803	...	...	3	Boiling	...	0.003 (0.1) max	...	169
2205	S31803	...	Sour well production fluid in equilibrium with 1 psi H_2S and 1200 psi CO_2	25	200	30 d	.006 (0.25)	...	207
2205	S31803	...	Sweet well production fluid, in equilibrium with 1200 psi CO_2	5	150	30 d	.003 (0.1) max	...	207
2205	S31803	...	With 0.1 atm, H_2S, 10 atm CO_2	...	100	14 d	...	No pitting	237
2205	S31803	...	With 0.1 atm, H_2S, 10 atm CO_2	...	120	14 d	...	Pitting 0.15 (6)	237
2205	S31803	...	With 0.1 atm, H_2S, 10 atm CO_2	...	150	14 d	...	Pitting 0.39 (16)	237
301	S30100	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	...	100 (212)	...	Good	Pitting	253
301	S30100	...	...	Saturated	100 (212)	...	Good	Pitting	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	100 (212)	...	Good	Pitting	253
302	S30200	...	...	Saturated	100 (212)	...	Good	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	100 (212)	...	Resistant	Pitting	253
303	S30300	...	...	...	100 (212)	...	Good	Pitting	253
303	S30300	...	...	Saturated	100 (212)	...	Questionable	Pitting	253
303	S30300	...	...	Saturated	100 (212)	...	Good	Pitting	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	100 (212)	...	Good	Pitting	253
304	S30400	...	...	Saturated	100 (212)	...	Good	Pitting	253

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Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Agriculture (fertilizer); no aeration; slight to moderate agitation. Plus 3.5% hydrofluosilicic acid	4.7	27 (80)	35 d	0.07 (2.6)	Severe pitting; crevice attack	89
304	S30400	...	Chemical (distillation) processing; no aeration; rapid agitation. Plus 1% sodium hydroxide	5.4	104 (220)	58 d	0.003 (0.1) max	Crevice attack	89
304	S30400	...	Chloride with 3% water, and 0.7% ferrous chloride	...	...	147 d	0.005 (0.2)	Slight pitting; crevice attack	89
304	S30400	...	Lab test. Remainder water	25	60 (140)	4 d	Resistant	Slight pitting	89
304	S30400	...	Lab test. Remainder water (vapors, liquid)	25	60 (140)	4.5 d	Resistant	Slight pitting	89
304	S30400	...	Lab test. Sodium chloride spray	20	35 (95)	84 d	0.010 (0.4)	Severe pitting	89
304	S30400	...	Lab test; strong aeration; no agitation	4	91 (195)	1 d	0.38 (15)	Moderate pitting	89
304	S30400	...	Mining (sulfur); strong aeration; rapid agitation. Waste brine with 1 g/L calcium chloride, and 250 ppm hydrogen sulfide (line)	~12	44 (112)	17 d	4 (156)	Severe pitting; crevice attack	89
304	S30400	...	No aeration; no agitaion. Plus acidic salt stripping solution with 70 g/L chloride, 50 g/L sulfate, 20-25 g/L nitrate, 4-5 g/L thorium, 1 g/L ferric ion, sulfuric acid 0.1*N*, and pH approx. 0.5	10.5	31 (86)	21 d	0.45 (18)	Slight pitting	89
304	S30400	...	No aeration; no agitation. Sodium chloride solution, pH 8.5	...	8 (17)	90 d	0.005 (0.2)	Severe pitting, crevice attack	89
304	S30400	...	No aeration; no agitation; low-carbon grade; 0.03% maximum. Sodium chloride solution, pH 8.5	...	8 (17)	90 d	0.003 (0.1)	Severe pitting, crevice attack	89
304	S30400	...	No aeration; rapid agitation. Plus 8% sodium hydroxide, 1% sodium chlorate, 1% ammonia, and the remainder water (ammonia still)	50	204 (400)	27 d	0.1 (4)	...	89
304	S30400	...	No aeration; rapid agitation. Sodium chloride bittern plus chloride ion 5N, 55 g/L sulfate ion, 41 g/L magnesium ion, sodium and potassium ions balance of cations, and pH 2-5 (heat exchanger). Stress corrosion cracking	~14	77 (170)	90 d	0.09 (3.6)	...	89
304	S30400	...	No aeration; rapid agitation. Sodium chloride solution, with 60 g/L sodium sulfate and 7 g/L sodium hydroxide (crystallizer tank)	~22	9 (48)	119 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; rapid agitation. With carbon over the standard maximum. Vapors from boiling saturated sodium chloride solution (evaporator)	...	99 (210)	210 d	0.003 (0.1)	Severe pitting, crevice attack	89
304	S30400	...	Slight to moderate aeration; no agitation. Plant waste effluent with 4-5% solids, chlorides, carbonates, sulfates, sulfides and organic salts, water remainder, pH 10	2	16 (60)	105 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Slight to moderate aeration; rapid agitation. Saturated sodium chloride solution (Oliver vacuum filter)	...	32 (90)	90 d	0.030 (1.2)	Severe pitting, crevice attack	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Sodium chloride spray, pH 8.5	...	8 (17)	90 d	0.003 (0.1)	Severe pitting, crevice attack	89
304	S30400	...	Slight to moderate aeration; rapid agitation. With carbon over the standard maximum. Sodium chloride brine with oxidizing materials from combustion products of gas flame (open evaporator)	50 max	93 (200)	14 d	0.23 (9)	Moderate pitting; crevice attack	89
304	S30400	...	Slight to moderate aeration; rapid agitation; low-carbon grade: 0.03% C maximum. Sodium chloride spray, pH 8.5	...	8 (17)	90 d	0.003 (0.1)	Slight pitting, crevice attack	89
304	S30400	...	Slight to moderate aeration; rapid agitation; low-carbon grade; 0.03% C maximum. Sodium chloride brine with oxidizing materials from combustion products of gas flame (open evaporator)	50 max	93 (200)	14 d	0.55 (22)	Moderate pitting; crevice attack	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Saturated sodium chloride brine, some oxidizing materials from products of combustion of gas flame	...	82 (180)	52 d	0.018 (0.7)	Severe pitting, crevice attack	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Saturated to 15.3% sodium chloride solution (alternate immersion)	...	16-27 (60-80)	160 d	0.005 (0.2)	Crevice attack	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Sodium chloride slurry with approx. 12% potassium chloride (Dorr thickener, center well)	~14	25 (77)	38 d	0.008 (0.3)	Slight pitting	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. With carbon over the standard maximum. Saturated sodium chloride brine, some oxidizing materials from products of combustion of gas flame	...	82 (180)	52 d	0.010 (0.4)	Severe pitting, crevice attack	89
304	S30400	...	Soap processing; no aeration; no agitation. Saturated salt solution of glycerine and water, with 1-80% glycerine (Wooster-Sanger evaporator, vapors)	...	60-104 (140-220)	91 d	0.008 (0.6)	Severe pitting; crevice attack	89
304	S30400	...	Soap processing; plus salt and crude glycerine, 7-25% solids, water vapor, pH 7-9	...	88 (190)	24 d	Resistant	...	89
304	S30400	...	Soap processing; slight to moderate aeration; rapid agitation. Plus sodium chloride; sodium sulfate, glycerine, pH 6-10 (vertical tube evaporator)	...	60-66 (140-150)	1235 d	0.003 (0.1) max	Severe pitting; crevice attack	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9. 10-12% glycerine, mud and water	...	29 (85)	105 d	0.15 (6)	Severe pitting, crevice attack	89
304	S30400	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9. 10-12% glycerine, mud and water	...	29 (85)	105 d	0.10 (4)	Severe pitting	89
304	S30400	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9. 10-12% glycerine, mud and water	...	29 (85)	105 d	0.003 (0.1)	Moderate pitting: maximum; crevice attack	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.25% aluminum chloride hydrate, 100 psi	18	74 (165)	65 d	0.003 (0.1) max	...	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.25% aluminum chloride hydrate	18	71 (160)	65 d	0.015 (0.6)	Severe pitting	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.03% total sodium oxide and approx. 0.003% free sodium oxide, pressure 110 psi	18	71 (160)	46 d	0.010 (0.4)	Slight pitting; crevice attack	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.03% total sodium oxide, approx. 0.003% free sodium oxide, pressure 110 psi.	18	60 (140)	46 d	0.020 (0.8)	Crevice attack	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Residual soap with 0.25% aluminum chloride hydrate (filter)	18	71 (160)	65 d	0.018 (0.7)	Severe pitting	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Residual soap with 0.25% aluminum chloride hydrate	18	74 (165)	65 d	0.003 (0.1) max	...	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Residual soap with approx. 0.03% total sodium oxide and approx. 0.0003% free sodium oxide	18	74 (165)	65 d	0.005 (0.2)	Crevice attack	89
304	S30400	...	Soap processing; strong aeration; rapid agitation. Residual soap with approx. 0.03% total sodium oxide and approx. 0.003% free sodium oxide	18	60 (140)	65 d	0.010 (0.4)	Crevice attack	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Soap processing; strong aeration; slight to moderate agitation; welded. Sodium chloride and 13-17% sodium sulfate, 10-12% glycerine, spent soap lye treated with ferric chloride and sulfuric acid to pH 4.5, mud and water	...	29 (85)	105 d	0.03 (1)	Severepitting, crevice attack	89
304	S30400	...	Strong aeration. Sodium chloride bittern (heat-exchanger head)	...	76 (169)	168 d	0.015 (0.6)	Severe pitting; stress corrosion cracking	89
304	S30400	...	Strong aeration; rapid agitation. Plus 4.5% potassium chloride	5	19 (67)	35 d	0.003 (0.1) max	...	89
304	S30400	...	Strong aeration; rapid agitation. Sodium chloride solution with 39 g/L free ammonia, 1.5 g/L fixed ammonia as ammonium chloride, 19 g/L carbon dioxide, and 0.5 g/L hydrogen sulfide (piping)	~21.2	63 (145)	174 d	0.003 (0.1) max	Severe pitting	89
304	S30400	...	Strong aeration; rapid agitation. With carbon over the standard maximum. Plus sodium chloride and potassium chloride	...	54 (130)	45 d	0.06 (2.2)	Crevice attack	89
304	S30400	...	Strong aeration; slight to moderate agitation. Purified sodium chloride slurry from vacuum pans with approx. 75% brine, and approx. 25% salt crystals	...	32-38 (90-100)	90 h	0.003 (0.1) max	Slight pitting, crevice attack	89
304	S30400	...	Strong aeration; slight to moderate agitation. Spent brine mine water from Frasch process with 500-1000 ppm calcium carbonate, 150-200 ppm hydrogen sulfide, 75-100 ppm polysulfides, 4-10 ppm thiosulfates as hydrogen sulfide, pH 6-6.8	~1.6	49 (120)	67 d	0.003 (0.1)	Severe pitting	89
304	S30400	...	Tanning; plus pickle liquor with 0.25-0.5% sulfuric acid	~7	16-21 (60-70)	180 d	0.06 (2.2)	...	89
304	S30400	...	Tanning; plus pickle liquor with 0.25-0.5% sulfuric acid (above liquor level)	~7	16-21 (60-70)	180 d	0.003 (0.1) max	...	89
304	S30400	...	Tanning; slight to moderate agitation. Acidified with sulfuric acid, petroleum solvent added, pH 2.5 (sheepskin degreasing drum)	12	...	180 d	0.003 (0.1)	...	89
304	S30400	...	Tanning; sodium chloride plus sodium sulfate	...	...	180 d	0.005 (0.2)	...	89
304	S30400	...	Textile processing; lab test; rapid agitation	10	66 (150)	4 d	0.018 (0.7)	...	89
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	...	100 (212)	...	Good	Pitting	253
304L	S30403	...	...	Saturated	100 (212)	...	Good	Pitting	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	100 (212)	...	Good	Pitting	253
304LN	S30453	...	...	Saturated	100 (212)	...	Good	Pitting	253
316	S31600	...	...	3	Boiling	...	0.005 (0.2)	...	51
316	S31600	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	100 (212)	...	Resistant	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	Saturated	100 (212)	...	Good	Pitting	253
316	S31600	...	Brine production; strong aeration; slight to moderate agitation. Sodium chloride brine, with 18 g/L sodium sulfate, 18 g/L sodium carbonate and 1 g/L sodium hydroxide	~23.5	Room to 71 (160)	225 d	Resistant	...	89
316	S31600	...	Lab test. Remainder water	25	60 (140)	4 d	Resistant	...	89
316	S31600	...	Lab test. Remainder water (vapors, liquid)	25	60 (140)	4.5 d	Resistant	Slight pitting	89
316	S31600	...	Lab test. Sodium chloride spray.	20	35 (95)	84 d	0.003 (0.1) max	Slight pitting	89
316	S31600	...	Lab test; strong aeration; no agitation	4	91 (195)	1 d	0.003 (0.1) max	...	89
316	S31600	...	No aeration, rapid agitation. Sodium chloride brine with 30-50 g/L sodium chlorate, 1-1.5 ppm iron, 1-1.5 ppm mercury and 0.2% sodium hypochlorite as chlorine	~19	10 (50)	90 d	0.08 (3)	Severe pitting; crevice attack	89
316	S31600	...	No aeration; no agitaion. Acidic salt stripping solution with 70 g/L chloride, 50 g/L sulfate, 20-25 g/L nitrate, 4-5 g/L thorium, 1 g/L ferric ion, sulfuric acid 0.1*N*, and pH approx. 0.5	10.5	31 (86)	21 d	0.4 (16)	Severe pitting; crevice attack	89
316	S31600	...	No aeration; no agitation. Sodium chloride solution, pH 8.5	...	8 (17)	90 d	0.003 (0.1) max	Severe pitting; crevice attack	89
316	S31600	...	No aeration; rapid agitation. Plus 1% sodium hydroxide	4-5	104 (220)	58 d	0.003 (0.1) max	Crevice attack	89
316	S31600	...	No aeration; rapid agitation. Plus 8% sodium hydroxide, 1% sodium chlorate; 1% ammonia, and the remainder water (ammonia still)	50	204 (400)	27 d	.06 (2.3)	...	89
316	S31600	...	No aeration; rapid agitation. Sodium chloride bittern plus chloride ion 5N, 55 g/L sulfate ion, 41 g/L magnesium ion, sodium and potassium ions balance of cations, and pH 2-5 (heat exchanger)	~14	77 (170)	90 d	0.15 (6)	Severe pitting	89
316	S31600	...	No aeration; rapid agitation. Sodium chloride solution, with 60 g/L sodium sulfate and 7 g/L sodium hydroxide (crystallizer tank)	~22	9 (48)	119 d	0.003 (0.1) max	...	89
316	S31600	...	No aeration; rapid agitation. Vapors from boiling saturated sodium chloride solution (evaporator)	...	99 (210)	210 d	0.003 (0.1) max	Moderate pitting; crevice attack	89
316	S31600	...	No aeration; slight to moderate agitation. Plus 3.5% hydrofluosilicic acid	4.7	27 (80)	35 d	0.02 (0.7)	Slight pitting; crevice attack	89
316	S31600	...	pH 4 dynamic exposure	0.1	20-80	112 d	...	Pitting .03 (1)	187
316	S31600	...	pH 4 dynamic exposure	0.5	20-80	112 d	...	Pitting .07 (3)	187
316	S31600	...	pH 4 dynamic exposure	1.0	20-80	112 d	...	Pitting .13 (5)	187
316	S31600	...	pH 4 dynamic exposure	1.5	20-80	112 d	...	Pitting .19 (7)	187
316	S31600	...	pH 4 dynamic exposure	3.0	20-80	112 d	...	Pitting .30 (12)	187
316	S31600	...	pH 4 Static exposure	0.1	20-80	112 d	...	Pitting .16 (6)	187
316	S31600	...	pH 4 Static exposure	0.5	20-80	112 d	...	Pitting .20 (8)	187
316	S31600	...	pH 4 Static exposure	1.0	20-80	112 d	...	Pitting .35 (14)	187

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	pH 4 Static exposure	1.5	20-80	112 d	...	Pitting .40 (16)	187
316	S31600	...	pH 4 Static exposure	3.0	20-80	112 d	...	Pitting .45 (18)	187
316	S31600	...	pH 7 Static exposure	0.1	20-80	112 d	...	Pitting .01 (0.4)	187
316	S31600	...	pH 7 Static exposure	0.5	20-80	112 d	...	Pitting .03 (1)	187
316	S31600	...	pH 7 Static exposure	1.0	20-80	112 d	...	Pitting .04 (2)	187
316	S31600	...	pH 7 Static exposure	1.5	20-80	112 d	...	Pitting .05 (2)	187
316	S31600	...	pH 7 Static exposure	3.0	20-80	112 d	...	Pitting .05 (2)	187
316	S31600	...	pH 9 Static exposure	0.1	20-80	112 d	...	Pitting .01 (0.4)	187
316	S31600	...	pH 9 Static exposure	0.5	20-80	112 d	...	Pitting .03 (1)	187
316	S31600	...	pH 9 Static exposure	1.0	20-80	112 d	...	Pitting .04 (2)	187
316	S31600	...	pH 9 Static exposure	1.5	20-80	112 d	...	Pitting .05 (2)	187
316	S31600	...	pH 9 Static exposure	3.0	20-80	112 d	...	Pitting .05 (2)	187
316	S31600	Tube liner	Plus 0.5% acetic acid and 100 psi CO_2.	5	(75-150)	...	(0.1) max	...	235
316	S31600	Tube liner	Plus 0.5% acetic acid plus 1 psi H_2 plus 100 psi CO_2	...	(75-400)	...	(1.3)	Pitted	235
316	S31600	...	Plus 20 ppm Cu^{2+}	3	Room	...	0.025 (1.0)	...	51
316	S31600	...	Salt processing; no aeration; rapid agitation. Purified sodium chloride brine, acidified with hydrochloric acid to pH 3.5-4.5	...	109 (228)	18 d	7 (263)	...	89
316	S31600	...	Slight to moderate aeration; no agitation. Plant-waste effluent with 4-5% solids, chlorides, carbonates, sulfates, sulfides and organic salts, water remainder, pH 10	2	16 (60)	105 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Saturated sodium chloride solution (Oliver vacuum filter)	...	32 (90)	90 d	0.003 (0.1)	Slight pitting	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Sodium chloride brine with oxidizing materials from combustion products of gas flame (open evaporator)	50 max	93 (200)	14 d	1.07 (42)	Moderate pitting; crevice attack	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Sodium chloride spray, pH 8.5	...	8 (17)	90 d	0.003 (0.1) max	Crevice attack	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Plus 240 g/L ammonium perchlorate, 78 g/L sodium perchlorate, 2 g/L sodium chlorate, trace ammonium chloride and pH 4.8	~15.3	68-77 (155-170)	98 d	0.005 (0.2)	Severe pitting; crevice attack	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Saturated sodium chloride brine, some oxidizing materials from products of combustion of gas flame	...	82 (180)	52 d	0.06 (2.2)	Severe pitting; crevice attack	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Saturated 15.3% sodium chloride solution (alternate immersion)	...	16-27 (60-80)	160 d	0.003 (0.1)	Crevice attack	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Sodium chloride slurry with approx. 12% potassium chloride	~14	25 (77)	38 d	0.008 (0.3)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Sodium chloride slurry with 17.8% calcium chloride, 3.2% magnesium chloride, solid salt in suspension, pH 6.3 (limed); pH 5.3 (unlimed)	45.6	54 (129)	215 d	.03 (1.1)	Severe pitting; crevice attack	89
316	S31600	...	Soap processing; no aeration; no agitation. Saturated salt solution of glycerine and water, with 1-80% glycerine (Wooster-Sanger evaporator, vapors)	...	60-104 (140-220)	91 d	0.003 (0.1) max	Slight pitting; crevice attack	89
316	S31600	...	Soap processing; plus salt and crude glycerine, 7-25% solids, water vapor, pH 7-9	...	88 (190)	24 d	Resistant	...	89
316	S31600	...	Soap processing; slight to moderate aeration; rapid agitation. Sodium chloride plus sodium sulfate, glycerine, pH 6-10 (vertical tube evaporator)	...	60-66 (140-150)	1235 d	0.003 (0.1) max	...	89
316	S31600	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9, 10-12% glycerine, mud and water	...	29 (85)	105 d	0.08 (3)	Severe pitting; crevice attack	89
316	S31600	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9, 10-12% glycerine, mud and water	...	29 (85)	105 d	0.08 (3)	...	89
316	S31600	...	Soap processing; slight to moderate aeration; slight to moderate agitation; welded. Sodium chloride and 13-16% sodium sulfate, acid lye treated with alkali to pH 9, 10-12% glycerine, mud and water	...	29 (85)	105 d	0.003 (0.1) max	Crevice attack	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.25% aluminum chloride hydrate, 110 psi	18	74 (165)	65 d	0.001 (0.1) max	...	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.25% aluminum chloride hydrate	18	71 (160)	65 d	0.010 (0.4)	Severe pitting; crevice attack	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.03% total sodium oxide and approx. 0.003% free sodium oxide, pressure 110 psi	18	71 (160)	46 d	0.003 (0.1)	...	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Plus approx. 0.03% total sodium oxide, approx. 0.003% free sodium oxide, pressure 110 psi	18	60 (140)	46 d	0.010 (0.4)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Soap processing; strong aeration; rapid agitation. Residual soap with 0.25% aluminum chloride hydrate (filter)	18	71 (160)	65 d	0.010 (0.4)	Severe pitting	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Residual soap with 0.25% aluminum chloride hydrate	18	74 (165)	65 d	0.003 (0.1) max	...	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Residual soap with approx. 0.03% total sodium oxide and approx. 0.0003% free sodium oxide	18	74 (165)	65 d	0.003 (0.1)	...	89
316	S31600	...	Soap processing; strong aeration; rapid agitation. Residual soap with approx. 0.03% total sodium oxide and approx. 0.003% free sodium oxide	18	60 (140)	65 d	0.005 (0.2)	...	89
316	S31600	...	Soap processing; strong aeration; slight to moderate agitation; welded. Sodium chloride and 13-17% sodium sulfate, 10-12% glycerine, spent soap lye treated with ferric chloride and sulfuric acid to pH 4.5, mud and water	...	29 (85)	105 d	0.03 (1)	Severe pitting; crevice attack	89
316	S31600	...	Sodium chloride with 3% water and 0.7% ferrous chloride	...	...	147 d	0.003 (0.1)	Slight pitting; crevice attack	89
316	S31600	...	Strong aeration. Sodium chloride bitttern (heat exchanger head)	...	76 (169)	168 d	0.02 (0.6)	Severe pitting	89
316	S31600	...	Strong aeration; no agitation. Sodium chloride brine with 3 g/L calcium sulfate, 0.5% g/L sodium chlorate and traces of sodium hypochlorite and mercury	~23.6	65 (149)	31 d	0.5 (2)	...	89
316	S31600	...	Strong aeration; rapid agitation. Plus 4.5% potassium chloride	5	19 (67)	35 d	0.003 (0.1) max	...	89
316	S31600	...	Strong aeration; rapid agitation. Plus oil-field brine, 10% calcium and magnesium chlorides, 0.4% bromine, pH 6	0.1	65 (149)	144 d	0.4 (16)	Severe pitting	89
316	S31600	...	Strong aeration; rapid agitation. Saturated salt brine, hydrogen sulfide 0.15 g/L, pH 6.7	...	38 (100)	393 d	0.003 (0.1)	Severe pitting	89
316	S31600	...	Strong aeration; rapid agitation. Sodium chloride plus potassium chloride	...	54 (130)	45 d	0.06 (2.2)	Crevice attack	89
316	S31600	...	Strong aeration; rapid agitation. Sodium chloride solution with 39 g/L free ammonia, 1.5 g/L fixed ammonia as ammonium chloride, 19 g/L carbon dioxide, and 0.5 g/L hydrogen sulfide (piping)	~21.2	63 (145)	174 d	0.003 (0.1) max	Severe pitting	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Strong aeration; rapid agitation. Waste brine with 1 g/L calcium chloride, and 250 ppm hydrogen sulfide (line)	~12	44 (112)	17 d	1.2 (47)	Severe pitting; crevice attack	89
316	S31600	...	Strong aeration; slight to moderate agitation. Purified sodium chloride slurry from vacuum pans with approx. 75% brine, and approx. 25% salt crystals	...	32-38 (90-100)	90 d	0.003 (0.1) max	...	89
316	S31600	...	Strong aeration; slight to moderate agitation. Saturated sodium chloride solution with 10 g/L calcium chloride, 2 g/L calcium sulfate, pH 6.5	26	10 (50)	180 d	.008 (0.3)	...	89
316	S31600	...	Strong aeration; slight to moderate agitation. Spent brine mine water from Frasch process with 500-1000 ppm calcium carbonate, 150-200 ppm hydrogen sulfide, 75-100 ppm polysulfides, 4-10 ppm thiosulfates as hydrogen sulfide, pH 6-6.8	~1.6	49 (120)	67 d	0.003 (0.1)	Severe pitting	89
316	S31600	...	Tanning; plus pickle liquor with 0.25-0.5% sulfuric acid	~7	16-21 (60-70)	180 d	0.03 (1.2)	...	89
316	S31600	...	Tanning; plus pickle liquor with 0.25-0.5% sulfuric acid (above liquor level)	~7	16-21 (60-70)	180 d	0.003 (0.1) max	...	89
316	S31600	...	Tanning; slight to moderate agitation. Acidified with sulfuric acid, petroleum solvent added, pH 2.5 (sheepskin degreasing drum)	12	...	180 d	0.003 (0.1)	...	89
316	S31600	...	Tanning; sodium chloride plus sodium sulfate	...	...	180 d	0.003 (0.1)	...	89
316	S31600	...	Textile processing; rapid agitation	10	66 (150)	4 d	0.003 (0.1) max	...	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	100 (212)	...	Good	Pitting	253
316F	S31620	...	...	Saturated	100 (212)	...	Good	Pitting	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	100 (212)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated	100 (212)	...	Good	Pitting	253
316L	S31603	...	With 0.1 atm, H_2S, 10 atm CO_2	...	100	14 d	...	Pitting 0.15 (6)	237
316L	S31603	...	With 0.1 atm, H_2S, 10 atm CO_2	...	120	14 d	...	Pitting 0.47 (19)	237
316L	S31603	...	With 0.1 atm, H_2S, 10 atm CO_2	...	150	14 d	...	Pitting 1.08 (43)	237
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	100 (212)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated	100 (212)	...	Good	Pitting	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	100 (212)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated	100 (212)	...	Good	Pitting	253
317	S31700	...	No agitation. Acidic salt stripping solution with 70 g/L chloride, 50 g/L sulfate, 20-25 g/L nitrate, 4-5 g/L thorium, 1 g/L ferric ion, sulfuric acid 0.1*N*, and pH approx. 0.5	10.5	31 (86)	21 d	.13 (5.1)	Slight pitting; crevice attack	89

(Continued)

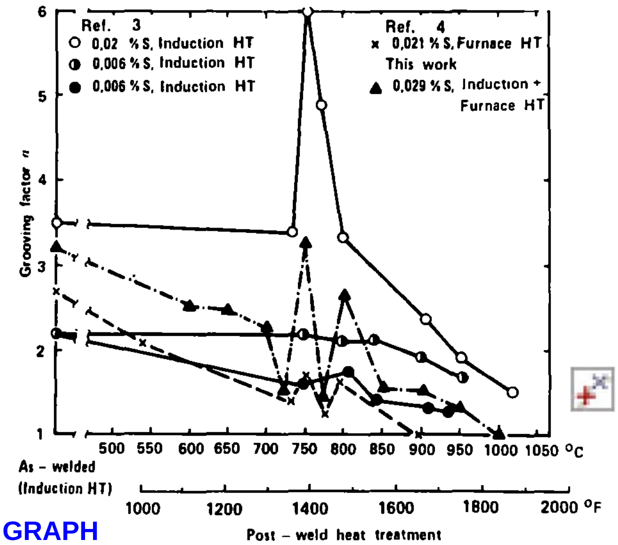
Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Salt processing; no aeration; rapid agitation. Purified sodium chloride brine, acidified with hydrochloric acid to pH 3.5-4.5	...	109 (228)	18 d	4.8 (190)	...	89
317	S31700	...	Strong aeration; no agitation. Sodium chloride brine with 3 g/L calcium sulfate, 0.5 g/L sodium chlorate and traces of sodium hypochlorite and mercury	~23.6	65 (149)	31 d	.018 (0.7)	...	89
317L	S31703	...	...	3	Boiling	...	0.03 (1.0)	...	169
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	100 (212)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated	100 (212)	...	Good	Pitting	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	100 (212)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated	100 (212)	...	Good	Pitting	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	100 (212)	...	Good	Pitting	253
321	S32100	...	...	Saturated	100 (212)	...	Good	Pitting	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	100 (212)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated	100 (212)	...	Good	Pitting	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	100 (212)	...	Good	Pitting	253
347	S34700	...	...	Saturated	100 (212)	...	Good	Pitting	253
403	S40300	...	...	Saturated	20 (68)	...	Good	Pitting	253
403	S40300	...	...	...	100 (212)	...	Questionable	Pitting	253
403	S40300	...	...	Saturated	100 (212)	...	Poor	Pitting	253
405	S40500	...	...	Saturated	20 (68)	...	Good	Pitting	253
405	S40500	...	...	...	100 (212)	...	Questionable	Pitting	253
405	S40500	...	...	Saturated	100 (212)	...	Poor	Pitting	253
409	S40900	...	...	Saturated	20 (68)	...	Good	Pitting	253
409	S40900	...	...	...	100 (212)	...	Questionable	Pitting	253
409	S40900	...	...	Saturated	100 (212)	...	Poor	Pitting	253
410	S41000	...	...	Saturated	20 (68)	...	Good	Pitting	253
410	S41000	...	...	...	100 (212)	...	Questionable	Pitting	253
410	S41000	...	...	Saturated	100 (212)	...	Poor	Pitting	253
416	S41600	...	...	Saturated	20 (68)	...	Good	Pitting	253
416	S41600	...	...	...	100 (212)	...	Questionable	Pitting	253
416	S41600	...	...	Saturated	100 (212)	...	Poor	Pitting	253
420	S42000	...	...	Saturated	20 (68)	...	Good	Pitting	253
420	S42000	...	...	...	100 (212)	...	Questionable	Pitting	253
420	S42000	...	...	Saturated	100 (212)	...	Poor	Pitting	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
430	S43000	...	...	...	100 (212)	...	Resistant	Pitting	253
430	S43000	...	...	Saturated	100 (212)	...	Questionable	Pitting	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
434	S43400	...	...	...	100 (212)	...	Resistant	Pitting	253
434	S43400	...	...	Saturated	100 (212)	...	Good	Pitting	253
AL 2205	S31803	...	...	3	Boiling	...	.003 (0.1)	...	219
AM-363	S36300	...	...	...	Room	...	Poor	...	120

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	Labortory test; slight to moderate aeration; slight to moderate agitation. Plus 240 g/L ammonium perchlorate, 78 g/L sodium perchlorate, 2 g/L sodium chlorate, trace ammonium chloride and pH 4.8	~15.3	68-77 (155-170)	98 d	0.003 (0.1)	Slight pitting	89
Carpenter 20	...	...	No aeration; rapid agitation. Plus 1% sodium hydroxide	4-5	104 (220)	58 d	0.003 (0.1) max	Crevice attack	89
Carpenter 20	...	...	No aeration; rapid agitation. Sodium chloride bittern plus chloride ion 5N, 55 g/L sulfate ion, 41 g/L magnesium ion, sodium and potassium ions balance of cations, and pH 2-5 (heat exchanger)	~14	77 (170)	90 d	0.10 (4)	Severe pitting; crevice attack	89
Carpenter 20	...	...	No aeration; rapid agitation. Sodium chloride brine with 30-50 g/L sodium chlorate, 1-1.5 ppm iron, 1-1.5 ppm mercury and 0.2% sodium hypochlorite as chlorine	~19	10 (50)	90 d	0.015 (0.6)	Severe pitting; crevice attack	89
Carpenter 20	...	...	No agitation. Acidic salt stripping solution with 70 g/L chloride, 50 g/L sulfate, 20-25 g/L nitrate, 4-5 g/L thorium, 1 g/L ferric ion, sulfuric acid 0.1*N*, and pH approx. 0.5	10.5	31 (86)	21 d	0.18 (7)	Slight pitting	89
Carpenter 20	...	...	Slight to moderae aeration; slight to moderate agitation. Saturated sodium chloride brine	...	71 (160)	204 d	0.003 (0.1) max	Crevice attack	89
Carpenter 20	...	...	Slight to moderate aeration; slight to moderate agitation; cast specimens. Saturated sodium chloride brine	...	71 (160)	204 d	0.003 (0.1) max	Crevice attack	89
Carpenter 20	...	...	Soap processing; no aeration; no agitation. Saturated salt solution of glycerine and water, with 1-80% glycerine (Wooster-Sanger evaporator, vapors)	...	60-104 (140-220)	91 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Soap processing; slight to moderate aeration; rapid agitation. Plus sodium chloride, sodium sulfate, glycerine, pH 6-10 (vertical tube evaporator)	...	60-66 (140-150)	1235 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Strong aeration. Sodium chloride bittern (heat exchanger head)	...	76 (169)	168 d	0.005 (0.2)	Severe pitting	89
Carpenter 20	...	...	Strong aeration; rapid agitation. Sodium chloride solution with 39 g/L free ammonia, 1.5 g/L fixed ammonia as ammonium chloride, 19 g/L carbon dioxide, and 0.5 g/L hydrogen sulfide (piping)	~21.2	63 (145)	174 d	0.003 (0.1)	...	89
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	100 (212)	...	Resistant	Pitting	253
F51	S31803	...	...	Saturated	100 (212)	...	Good	Pitting	253
Ferralium	S32550	...	...	3	Boiling	...	0.01 (0.4)	...	51
Ferralium	S32550	...	...	3	Boiling	...	0.01 (0.4)	...	169
Ferralium	S32550	...	Plus 20 ppm Cu^{++}	3	Room	...	0.01 (0.4)	...	51
Ferralium 255	S32550	...	...	3	Boiling	...	.01 (0.4)	...	219
T-317L	S31703	...	...	3	Boiling	...	.03 (1)	...	219



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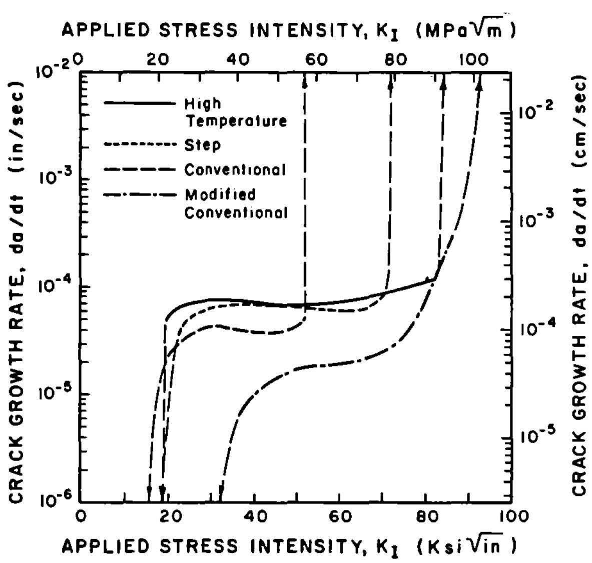
Low-alloy steel. Effect of annealing temperature on the susceptibility of grooving corrosion in electric resistance welded pipe. (Summary of the Masamura and Matsushima and Williams findings and findings established in cited source). Short-run test conditions involve welded specimens exposed to a 3.5% sodium chloride solution at 30 °C (86 °F) and anodically polarized to E_H = -0.3 V for 6 days. This susceptibility to grooving corrosion can be quantitatively described by a grooving factor (alpha). Source: C. Duran, E. Treiss, *et al.*, "The Resistance of High Frequency Inductive Welded Pipe to Grooving Corrosion in Salt Water," *Materials Performance*, Vol 25, 1986, 46.



Low-alloy steel. Comparison of crack growth rates for various heat treatments of 300M steel in 3.5% sodium chloride. Source: R. Padmanabhan and W.E. Wood, "Stress Corrosion Cracking Behavior of 300M Steel Under Different Heat Treated Conditions," *Corrosion*, Vol 41, Dec 1985, 691.

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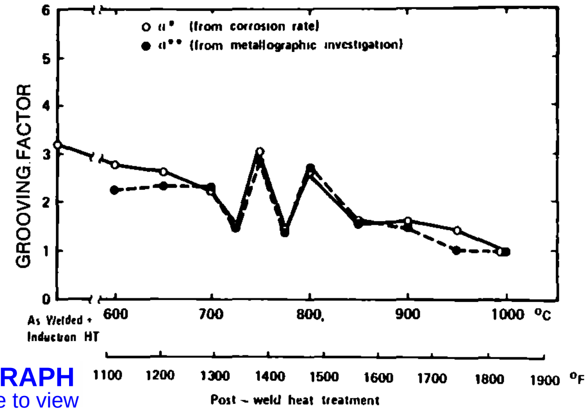

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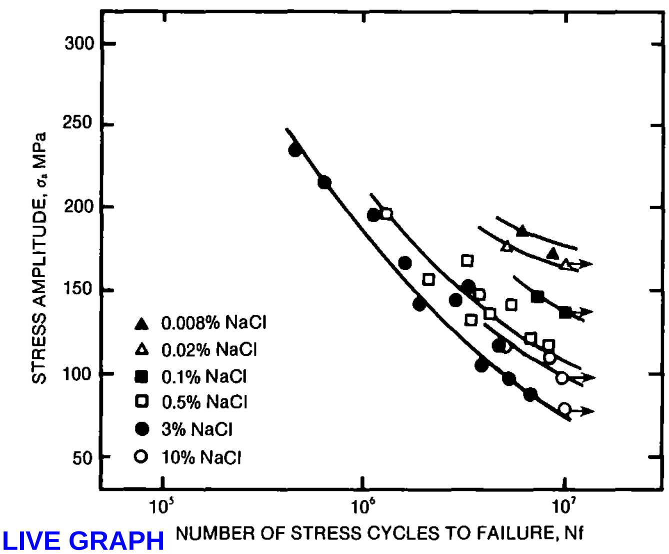
Low-alloy steel. Effect of post-weld heat treatment (annealing time, 30 min) on grooving corrosion in steel with a 0.029% sulfur content. Source: C. Duran, E. Treiss, *et al.*, "The Resistance of High Frequency Inductive Welded Pipe to Grooving Corrosion in Salt Water," in *Materials Performance,* Vol 25, 1986, 46.



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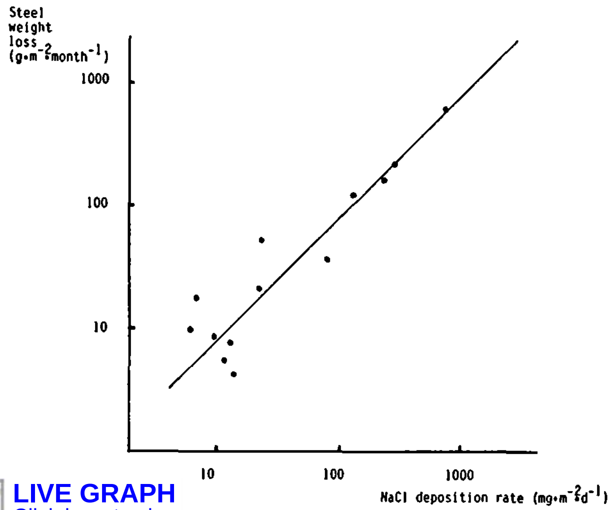
Steel. S-N curves (rotating bending test, 30 Hz) for AISI 1035 steel. Source: T. Okada and S. Hattori, "Relation Between Concentration of Salt Water and Corrosion Fatigue Strength on 0.37% Carbon Structural Steel," *Journal of Engineering Materials Technology*, Vol 107, July 1985, 236.



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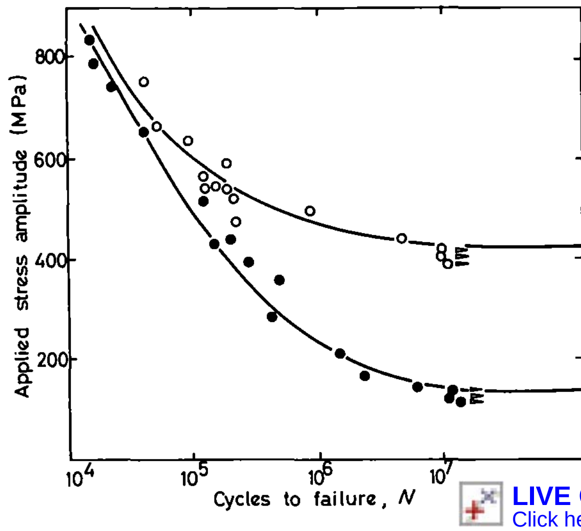
Steel. Corrosion vs. sodium chloride deposition rate. Corrosion on a painted steel surface generally begins at a defect in the coating with an initial loss of coating adhesion through cathodic delamination. Exposure to sodium chloride, a common corrosion stimulator that occurs in coastal and salt road areas, tends to give an alkaline subcoating liquid. Source: L. Igetoft, "Reactions on Painted Steel Under the Influence of Sulfur Dioxide, Sodium Chloride, and Combinations Thereof," *Industrial Engineering Chemistry, Product Research and Development*, Vol 24, Sept 1985, 376.



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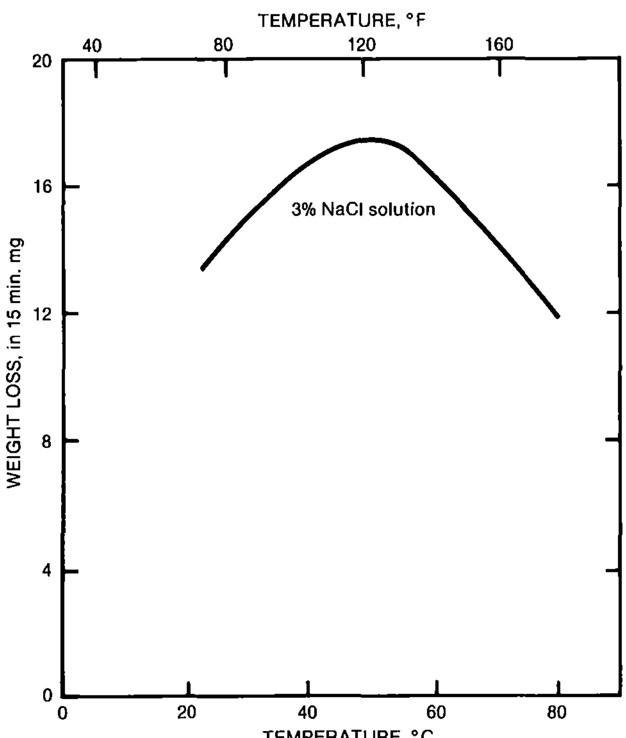
Maraging steel. S-N curves for 18 Ni maraging steel (yield strength 930 MPa) in air and 3.5 wt% sodium chloride solution. Open circle: air. Closed circle: sodium chloride. Source: T. Alp, Z. Husain, *et al.*, "Corrosion Fatigue Crack Initiation and Growth in 18 Ni Maraging Steel," *Journal of Material Science*, Vol 21, Sept 1986, 3265.



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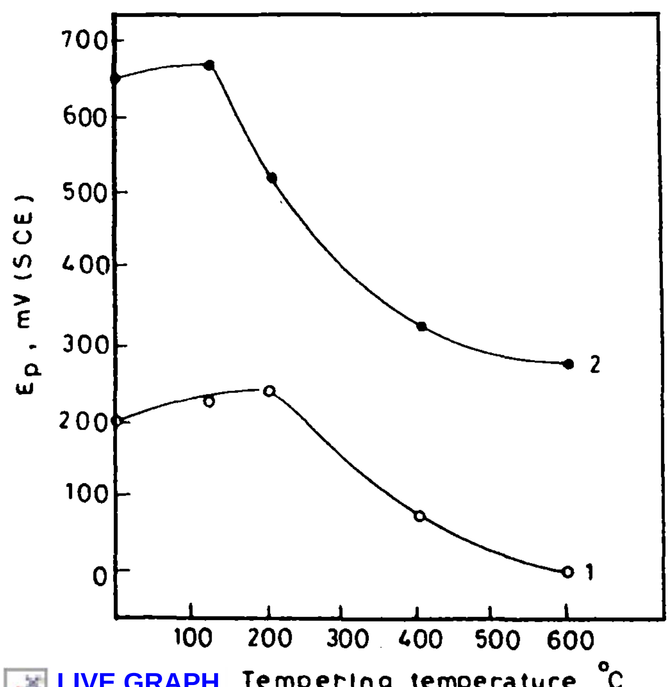
Carbon steel. Influence of temperature on the erosion rate of plain carbon steel in a vibratory cavitation device. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 313.



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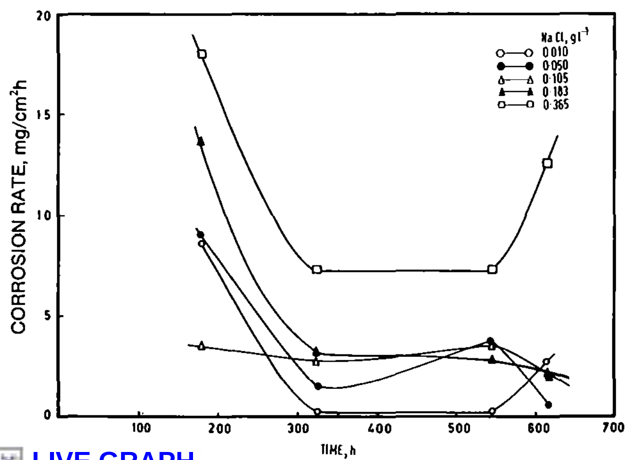
Carbon steel. Dependence of pitting corrosion potential on tempering temperature. Curve 1: 1 x 10^{-2} *M* sodium hydroxide, 1 x 10^{-2} sodium chloride. Curve 2: 1 x 10^{-1} *M* sodium hydroxide, 2 x 10^{-2} *M* sodium chloride. Source: S.M. Abd El-Haleem, S.S. Abd El Rehim, *et al.*, "Anodic Behavior and Pitting Corrosion of Plain Carbon Steel in NaOH Solutions Containing Chlorine Ions," *Surface Coating Technology*, Vol 27, Feb 1986, 172.



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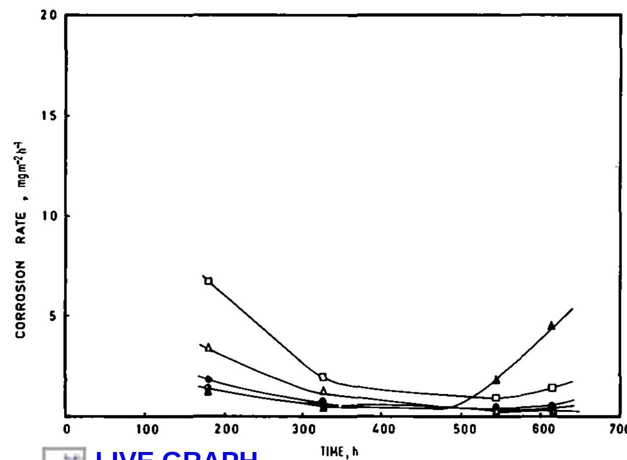
Carbon steel. Corrosion rate vs. time for carbon steel in 0.43 g/L calcium hydroxide solutions containing various concentrations of sodium chloride. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in the Presence of Corrosion Activators," *British Corrosion Journal*, Vol 20, Jan 1985, 33.



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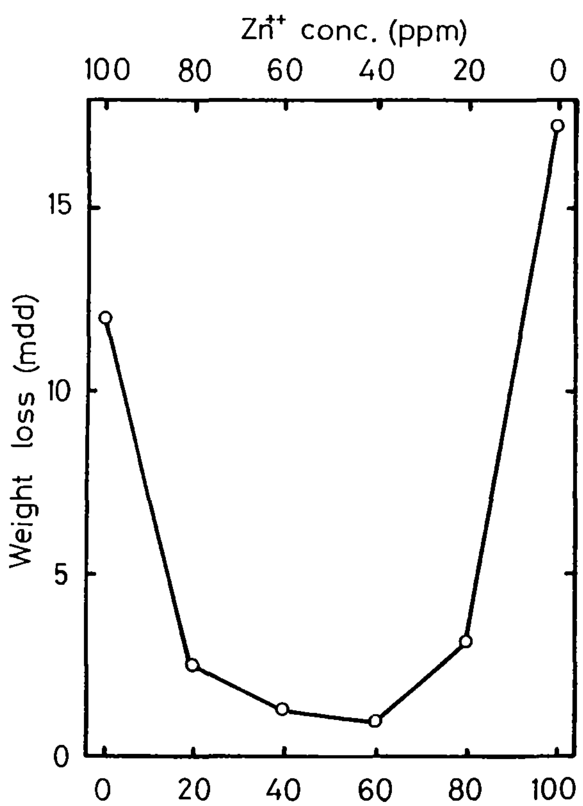
Carbon steel. Corrosion rate vs. time for carbon steel in 0.76 g/L calcium hydroxide solutions containing various concentrations of sodium chloride. Open circle: air. Closed circle: sodium chloride. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in the Presence of Corrosion Activators," *British Corrosion Journal*, Vol 20, Jan 1985, 33.



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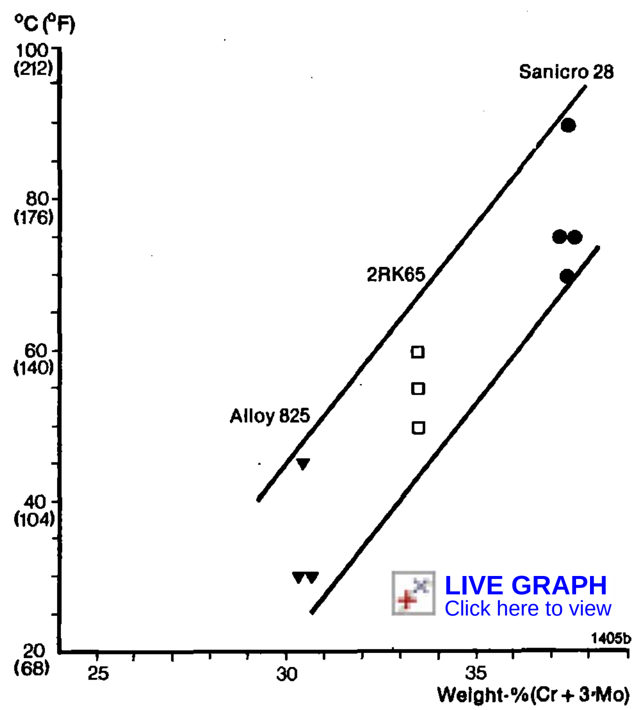
Stainless steel. Corrosion weight loss vs. concentration of HEDP and the Zn^{2+} ion in 0.3% sodium chloride solution. Source: I. Sekine and Y. Hirakawa, "Effect of 1-Hydorxyethylidene-1, 1-Diphosphonic Acid on the Corrosion of SS 41 Steel in 0.3% Sodium Chloride Solution," *Corrosion*, Vol 42, May 1986, 275.



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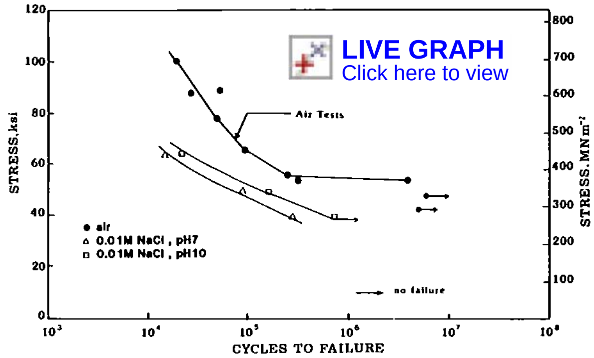
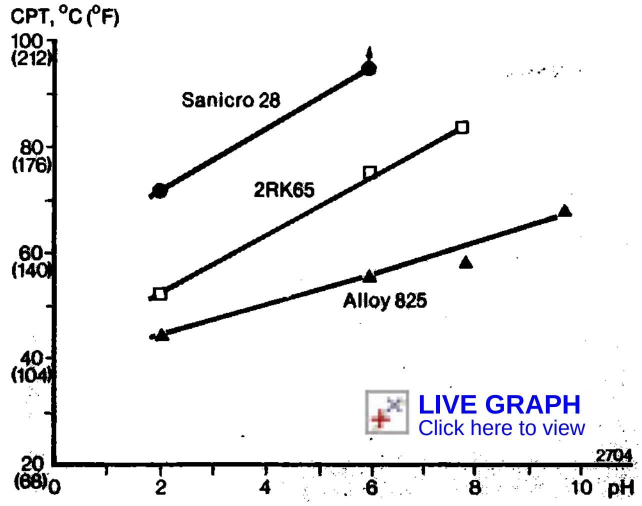
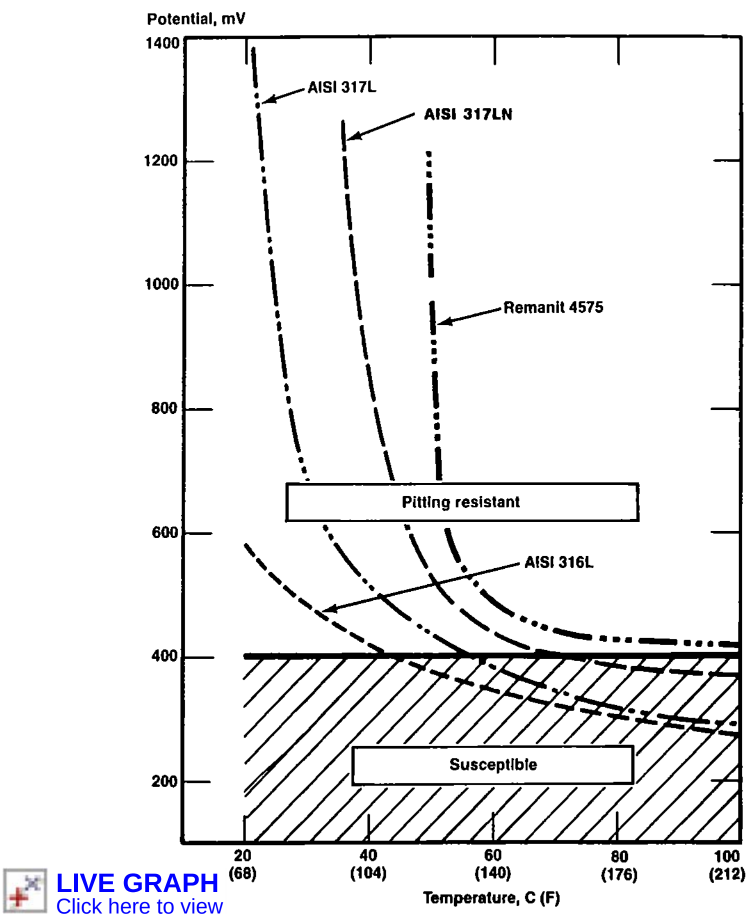
Stainless steel. Critical crevice temperatures at 200 mV SCE in a 3% sodium chloride aqueous solution, pH about 6, 15 min at each testing temperature. Sanicro 28 (Sweden) = ASTM B668; 2RK65 (Sweden) = ASTM B677; Alloy 825 = ASTM B423. Source: S. Bernhardsson, R. Mellstrom, *et al.*, "Performance of a Highly Alloyed Stainless Steel in Marine Environments," *Anti-Corrosion Methods and Materials*, Vol 32, April 1985, 11.



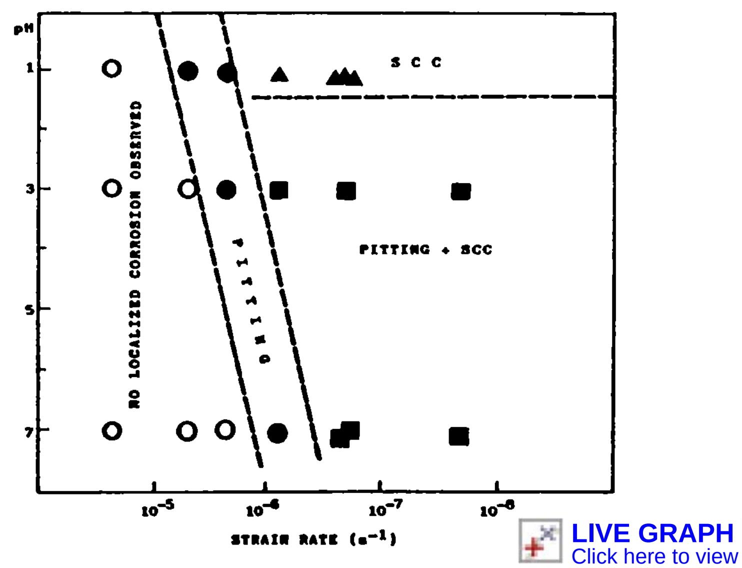
Stainless steel. S-N curves for type 403 stainless steel tested in air and in 0.01*M* sodium chloride solutions at pH 7 and 10. Source: H.M. Shalaby and V.K. Gouda, "Effect of Chloride Concentration and pH on Fatigue Crack Initiation Morphology of Type 403 Stainless Steel," *British Corrosion Journal*, Vol 20, June 1983, 126.



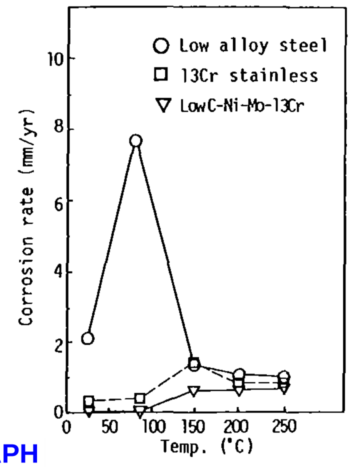
Stainless steel. Influence of pH on CPT at 400 mV SCE in 3% sodium chloride solutions. Sanicro 28 (Sweden) = ASTM B668. 2RK65 (Sweden) = ASTM B677. Alloy 825 = ASTM B423. Source: S. Bernhardsson, R. Mellstrom, *et al.*, "Performance of a Highly Alloyed Stainless Steel in Marine Environments," *Anti-Corrosion Methods and Materials*, Vol 32, April 1985, 8.



Stainless steel. Pitting potential of alloy 4575 and three standard austenitic stainless steels as a function of temperature in aerated 3% sodium chloride solution. Alloy 4575 is a ferritic stainless steel of nominal 28Cr-2.5Mo-4 Ni composition. Source: H.E. Chandler, "Ferritic Stainless Steel Combats Chloride Corrosion," *Metal Progress*, Vol 128, Oct 1985, 63-66.



Stainless steel. Localized corrosion morphology of AISI 304 steel at 110 °C in 5*M* sodium chloride solution. Source: F. Mancia and A. Tamba, "Slow Strain Rate Stress Corrosion Cracking of AISI 304 Stainless Steel in NaCl Solution and Its Prevention by Controlled Cathodic Protection," *Corrosion*, Vol 42, June 1986, 365.



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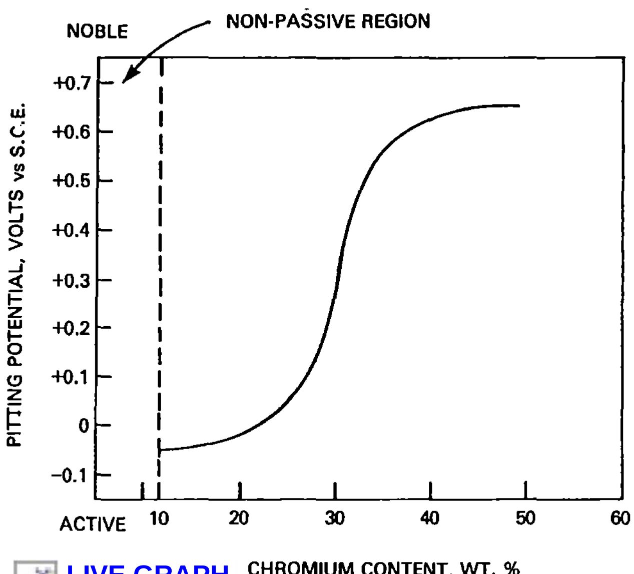
Stainless steel. Corrosion rate in 3.5% sodium chloride solution at 30 atm P_{CO_2}. Source: T. Kurisu, M. Kimura, *et al*, "Corrosion Resistance of Low C-Ni-13Cr Stainless Steels in CO_2/H_2O Environments," *Transactions of the Iron and Steel Institute of Japan*, Vol 25, April 1985, B-133.



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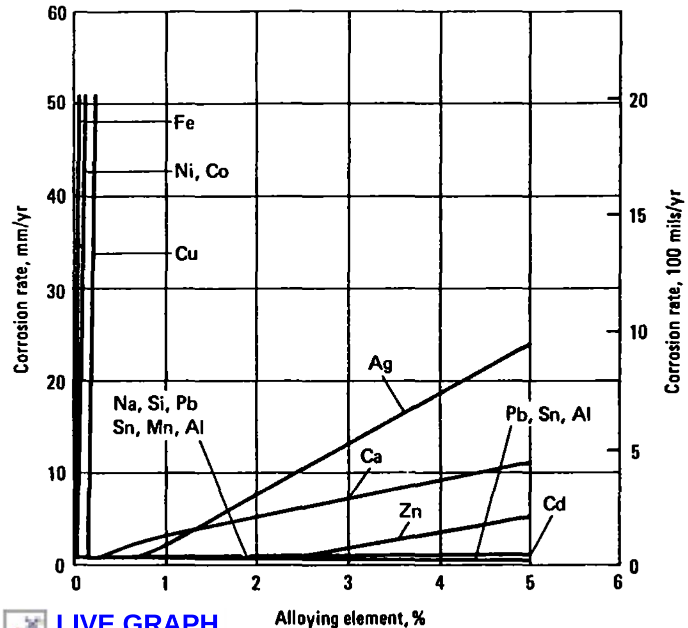
Stainless steel. Effect of chromium content on pitting potential of iron-chromium alloys in deaerated 0.1*N* sodium chloride at 25 °C. Source: A.J. Sedriks, "Effects of Alloy Composition and Microstructure on the Passivity of Stainless Steels," *Corrosion*, Vol 42, July 1986, 379.



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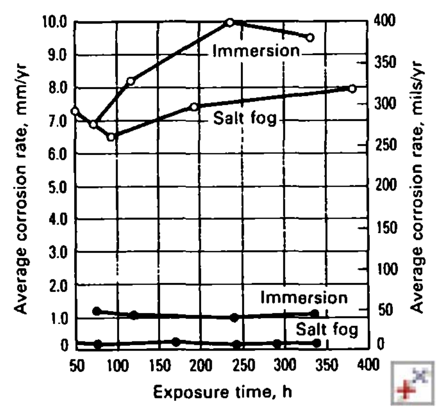
Magnesium. Effect of alloy content on corrosion rates of magnesium-base binary alloys tested in 3% sodium chloride solution. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 597.



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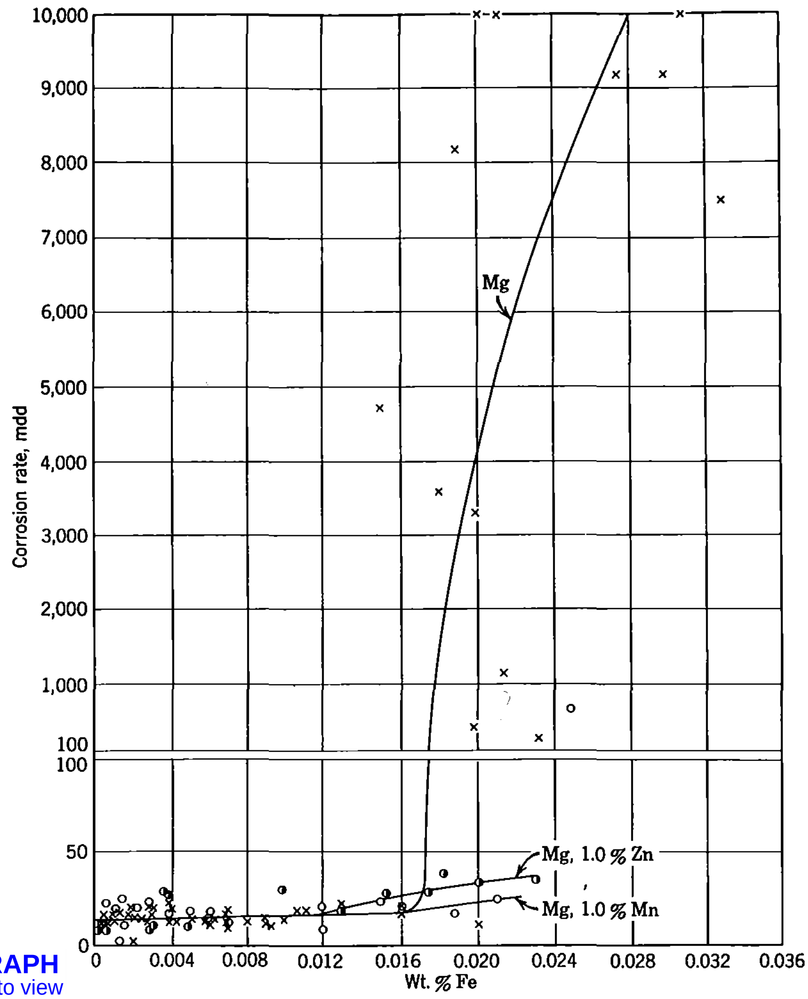
Analysis of die-cast plates, %	AM60A (O)	AZ91D (●)
Aluminum	6.2	9.7
Zinc	0.09	0.74
Manganese	0.22	0.19
Nickel	0.003	0.0018
Iron	0.005	0.006
Copper	0.03	0.0067

Magnesium. Corrosion rates of die cast magnesium in 5% sodium chloride salt spray and continuous-immersion exposure. Source: AMAX Magnesium.



LIVE GRAPH
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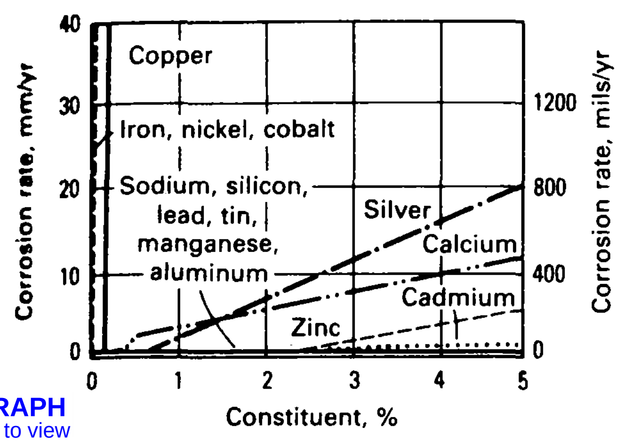
Magnesium. Corrosion of magnesium in 3% sodium chloride, alternate immersion, 16 weeks, showing tolerance limit for iron and beneficial effect of alloyed zinc and manganese. Source: Herbert H. Uhlig, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, John Wiley & Sons, New York, 1963, 308.



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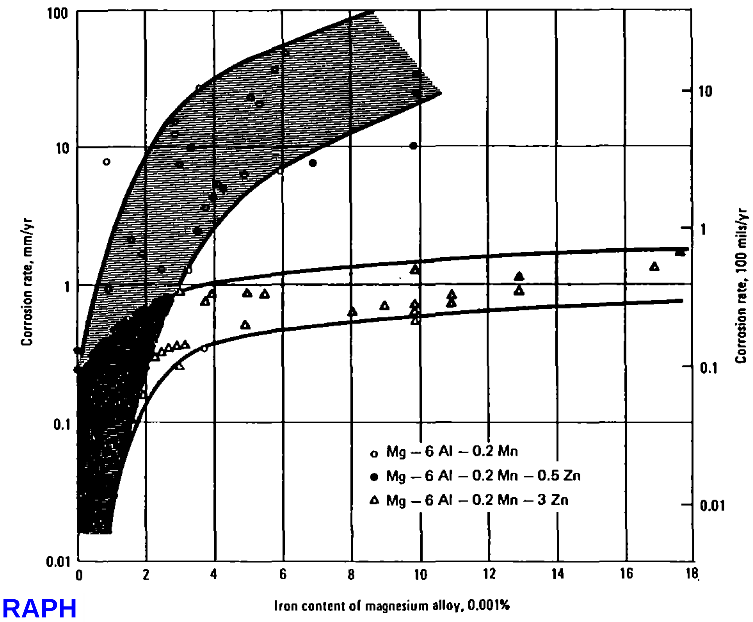
Magnesium. Effect of alloying and contaminant metals on the corrosion rate of magnesium as determined by alternate immersion in 3% sodium chloride solution. Source: J.D. Hanawalt, C.E. Nelson, and J.A. Peloubet, *Transactions of the AIME*, Vol 147, 1942, 273.



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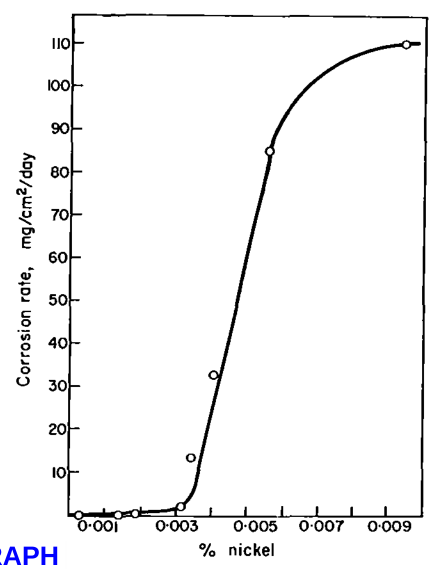
Magnesium. Effect of zinc content on relationship between iron content and corrosion rate for Mg-6Al-0.2Mn alloys in 3% sodium chloride solution. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 597.



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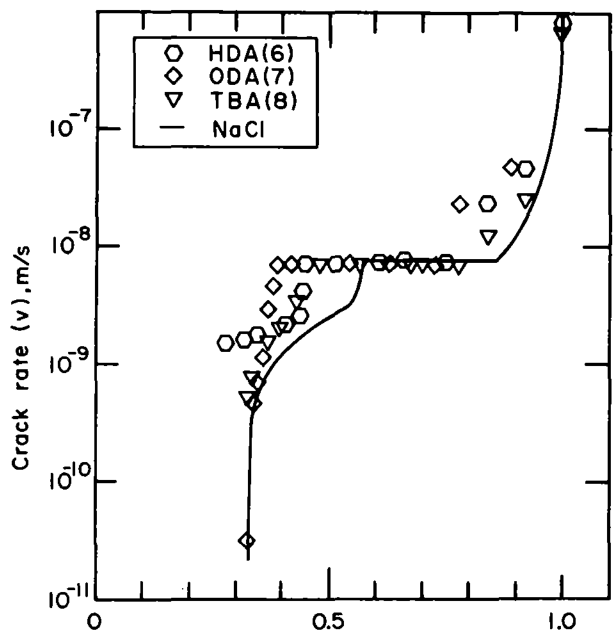
Magnesium. Tolerance limit for nickel shown by Mg-0.6% Zr alloy (ZA) when tested in 3% sodium chloride solution (total immersion conditions). Source: E.F. Emley, *Principles of Magnesium Technology*, Pergamon Press, Oxford, 1966, 685.



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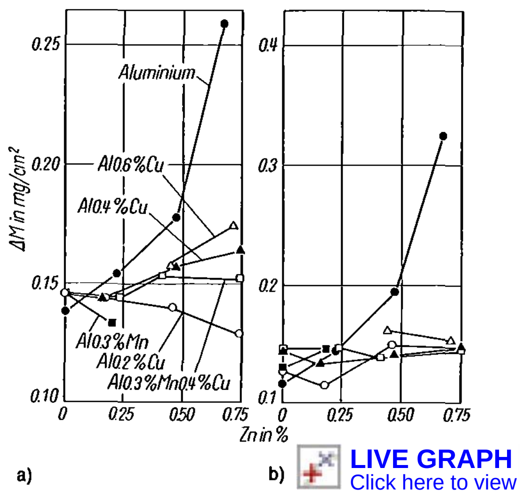
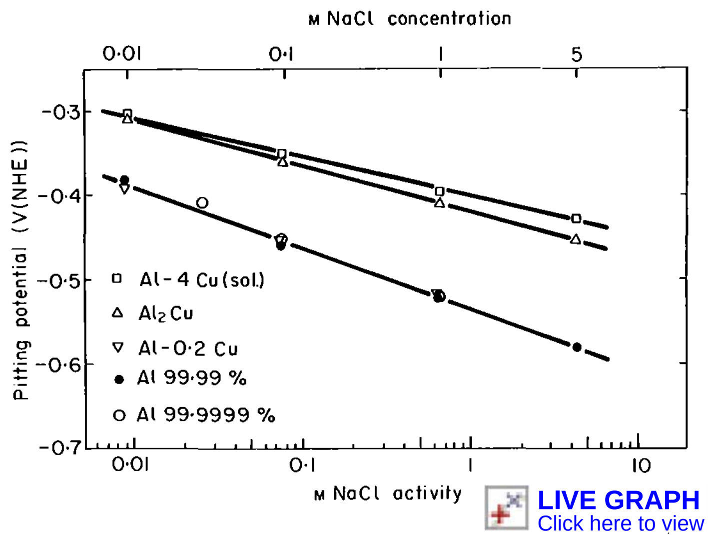
Aluminum. Normalized stress-corrosion cracking behavior of 7075-T651 alloy in 3.5 wt% sodium chloride and alkyl amine (HDA, ODA, and TBA, with the hexadecyl-, octadecyl-, and tributyl- groups, respectively). Solid line represents behavior in 3.5 wt% sodium chloride alone. Source: D. Tromans, "Effect of Organic Adsorbants on the Aqueous Stress Corrosion Cracking of AA 7075-T651 Aluminum Alloy," *Corrosion*, Vol 42, Oct 1986, 604.

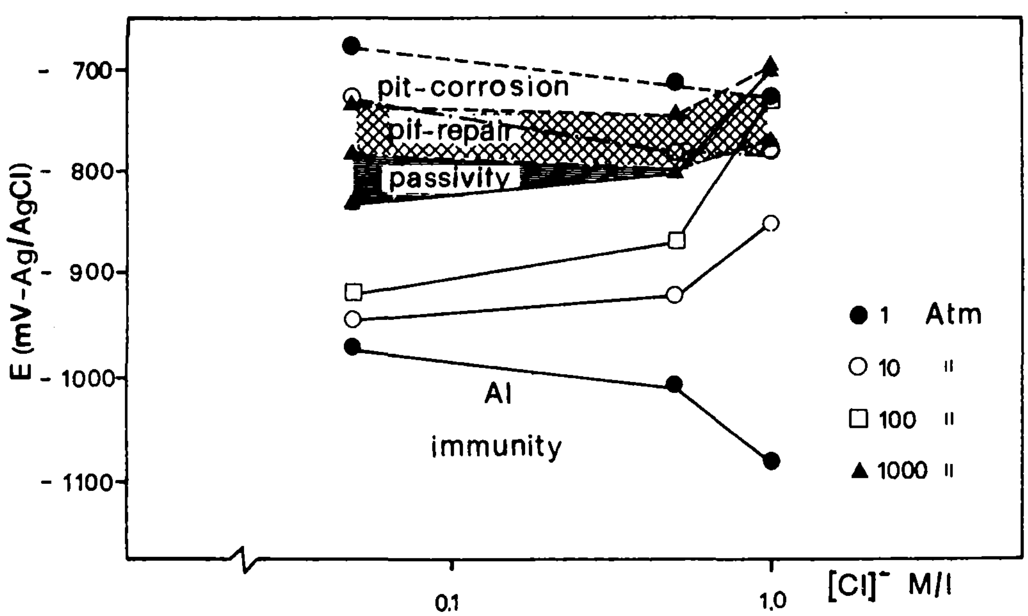


	Corrosion loss in mg/cm²	Pit density in 1/cm²	Maximum pit depth in mm
Aluminum	$1.7 \cdot 10^{-2}$	135	0.06
– 0.25% Zn	$2.7 \cdot 10^{-2}$	95	0.03
– 0.75% Zn	$2.8 \cdot 10^{-2}$	72	0.29
Al – 0.2% Cu	$4.1 \cdot 10^{-2}$	43	0.07
– 0.2% Cu – 0.5% Zn	$3.9 \cdot 10^{-2}$	50	<0.02
Al – 0.4% Cu	$7.5 \cdot 10^{-2}$	23	0.13
– 0.4% Cu – 0.25% Zn	$4.6 \cdot 10^{-2}$	23	0.07
Al – 0.3% Mn	$1.1 \cdot 10^{-2}$	57	<0.02
– 0.3% Mn – 0.25% Zn	$1.8 \cdot 10^{-2}$	105	<0.02

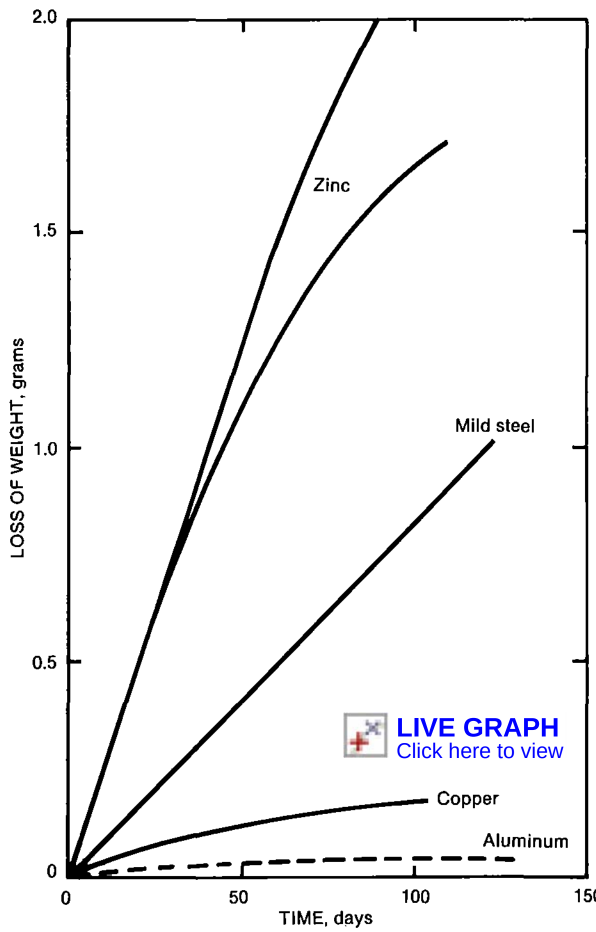
Aluminum. Effect of zinc content on corrosion mass loss after immersion for 100 h in 1*M* sodium chloride solution at 40 °C. (a) pH 6. (b) pH 3. Source: K. Tohma, N. Takahashi, *et al.*, "Compound Effects of Additions of Zn, Cu, and Mn on the Electrochemical Properties and Corrosion Resistance of Aluminum," *Aluminum*, Vol 61, April 1985, 278.



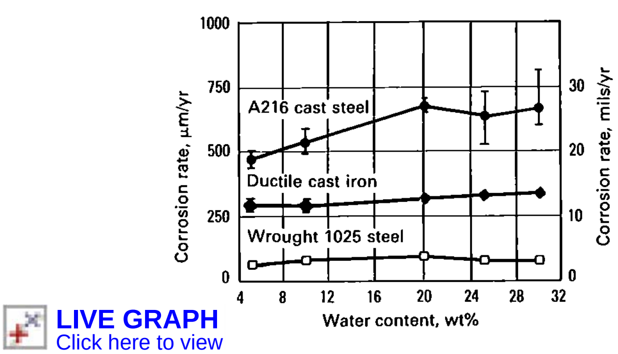
Aluminum. Effect of chloride concentration on the pitting potential of pure aluminum and various aluminum-copper alloys in deaerated sodium chloride solutions. Source: J.R. Galvele, "Pitting Corrosion," in *Treatise on Materials Science and Technology*, Vol 23, J.C. Scully, Ed., Academic Press, New York, 1983, 17.



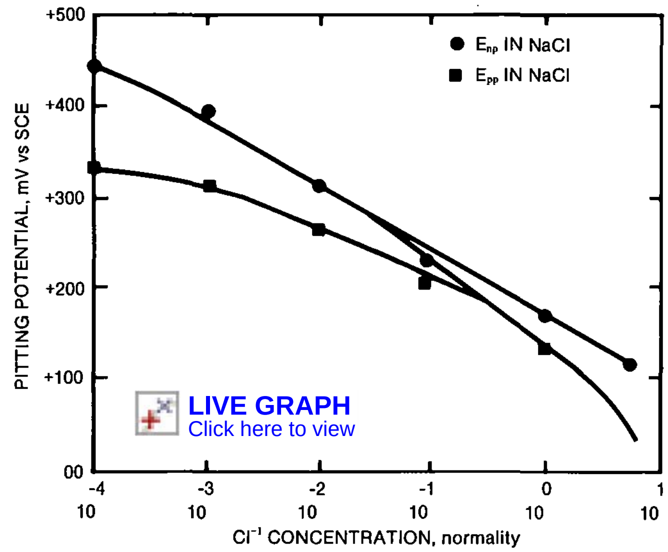
Aluminum. E_{corr} (solid line), E_p (broken line), and E_{pp} (dash-dot-dash line) potentials for aluminum corrosion in sodium chloride at different hydrostatic pressures. Source: A.M. Beccaria and G. Poggi, "Influence of Hydrostatic Pressure and Salt Concentration on Aluminum Corrosion in NaCl Solutions," *Corrosion*, Vol 42, Aug 1986, 475.



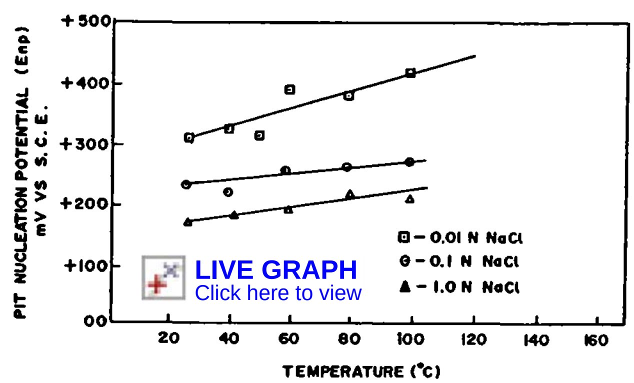
Various metals. Corrosion resistance of common metals in sodium chloride solutions. The specimen was 2.5 cm in diameter, 0.6 cm thick, with 4.35 cm^2 surface area. The corrosion loss in centimeters can be calculated by dividing weight loss by 4.35 and multiplying by the specific gravity of the metal. Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 54.



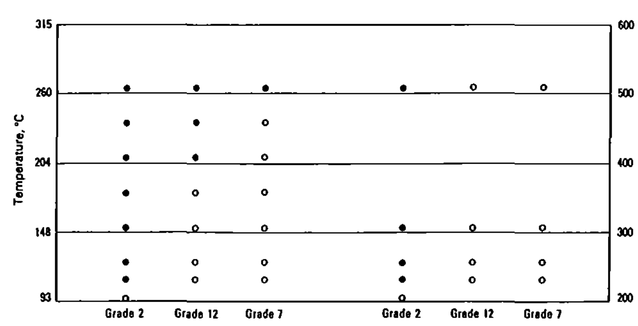
Cast iron. Effect of low levels of magnesium containing brine in sodium chloride on the general corrosion rate of cast irons and steel at 150 °C (300 °F). Test duration: 13 weeks. Source: R.E. Westerman and S.G. Pittman, "Corrosion of Candidate Iron-Base Waste Package Structural Barrier Materials in Moist Salt Environments," *Materials Research Society*, Vol 44, 1985, 282-285.



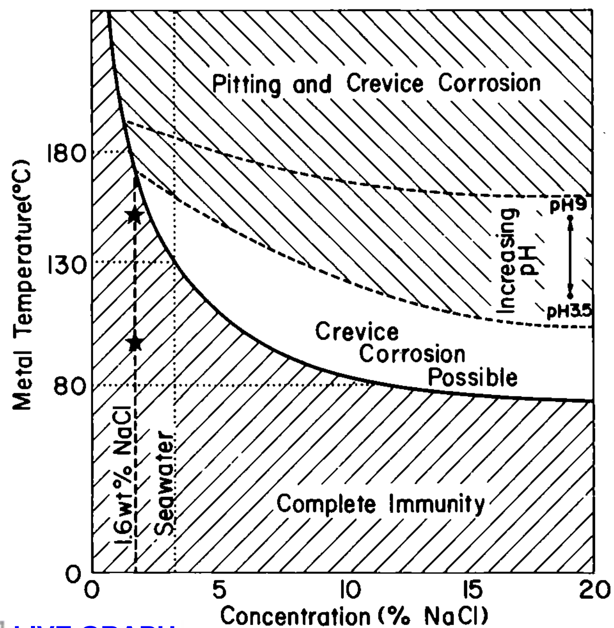
Zirconium. Variation of nucleation and pit passivation potentials for zirconium as a function of chloride ion concentration in sodium chloride. Source: G.C. Palit and H.S. Gadiyar, "Pitting Corrosion of Zirconium in Chloride Solution," *Corrosion*, Vol 43, March 1987, 144.



Zirconium. Pit nucleation potential of zirconium as a function of temperature in various concentrations of sodium chloride solutions. Source: G.C. Palit and H.S. Gadiyar, "Pitting Corrosion of Zirconium in Chloride Solution," *Corrosion*, Vol 43, March 1987, 144.



Titanium. Temperature guidelines for avoiding localized attack of grades 2, 7, and 12 titanium in pressure-bled tests in concentrated sea salt and sodium chloride slurries in the absence of crevices. Closed circle denotes susceptibility to localized attack. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 684.



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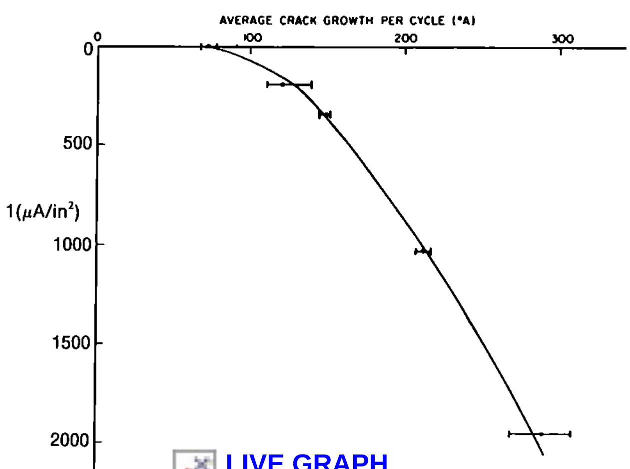
Titanium. Effect of temperature, chloride concentration, and pH on the localized corrosion of unalloyed titanium. Data on crevice corrosion of grade 2 titanium in 1.6 wt% sodium chloride are included for comparison. Source: P. McKay and D.B. Mitton, "An Electrochemical Investigation of Localized Corrosion on Titanium in Chloride Environments," *Corrosion*, Vol 41, Jan 1985, 61.



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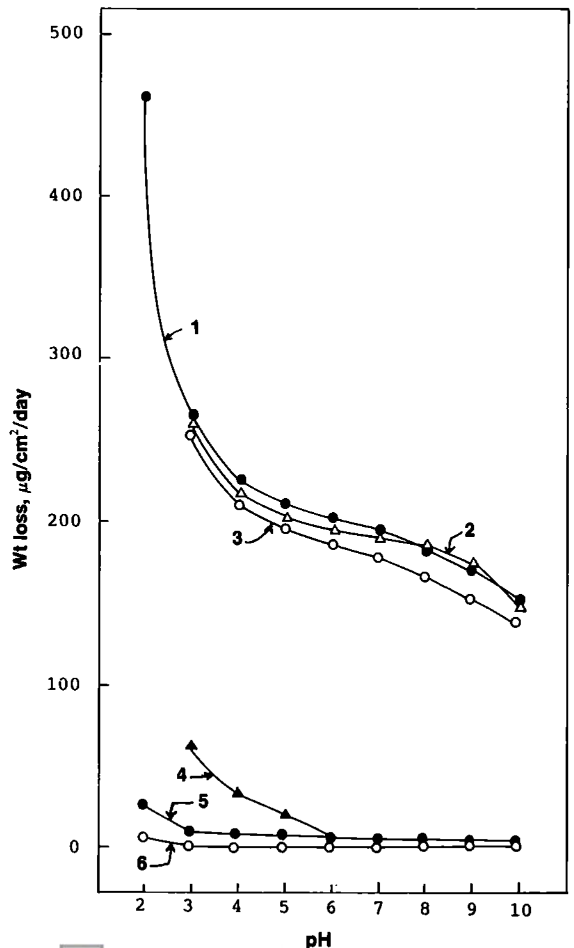
Copper. Average crack growth per cycle as a function of applied current in 3.5% sodium chloride for (90-10 cupronickel, CA 706). Source: D.P. Harvey, T.S. Sudarshan, *et al.*, "Corrosion Fatigue Behavior of 90/10 Copper-Nickel Cladding for Marine Structures," *Journal of Materials for Energy Systems*, Vol 7, Dec 1985, 272.



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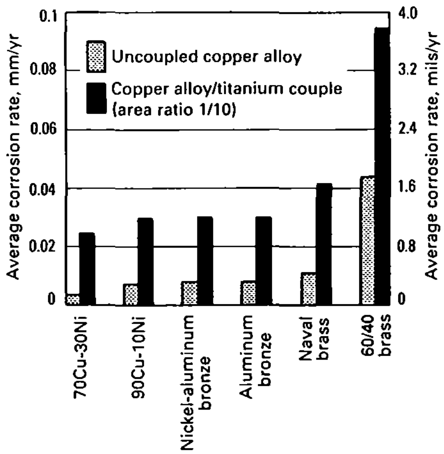
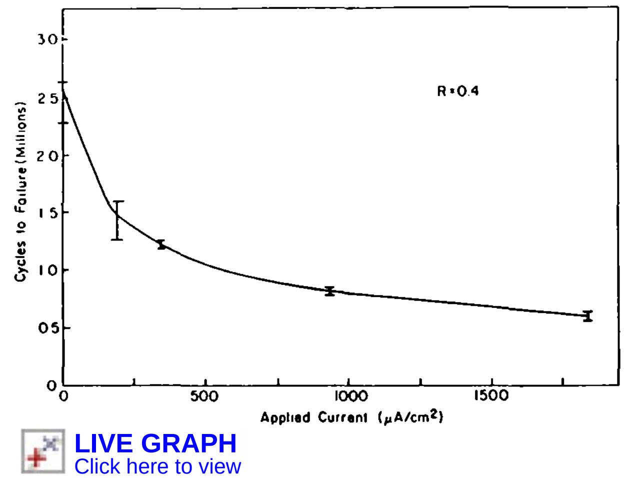
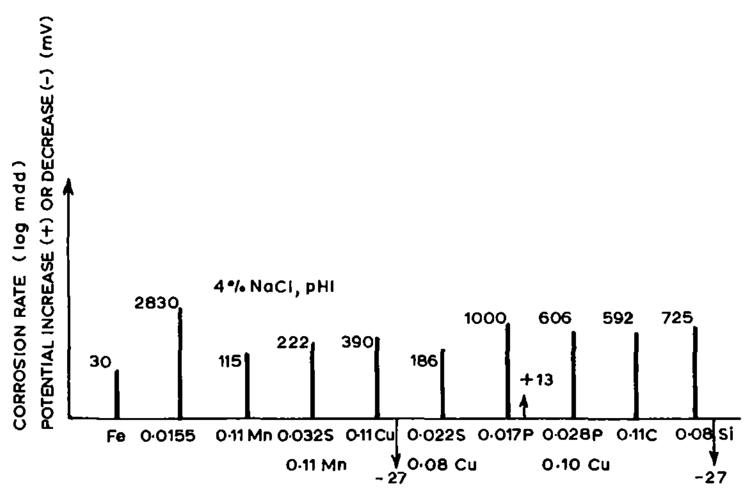
Copper. Effect of pH on corrosion rate of copper (as measured by weight loss) during 1 week of immersion in aerated solutions containing 3% sodium chloride and/or 0.2% benzotriazole at 60 °C. Curve 1: Copper sheet was immersed in 3% sodium chloride. Curve 2: Pretreated for 4 s in 0.2% benzotriazole at pH 10, then immersed in 3% sodium chloride. Curve 3: Pretreated for 5 s in 0.2% benzotriazole at pH 4, then immersed in 3% sodium chloride. Curve 4: Immersed in 3% sodium chloride and 0.2% benzotriazole and pH adjusted with acetic acid. Curve 5: Immersed in 3% sodium chloride and 0.2% benzotriazole. Curve 6: Immersed in 0.2% benzotriazole. The pH of all solutions (except that used to produce Curve 4) was adjusted with hydrochloric acid or potassium hydroxide. Source: C.H. Huang, "Corrosion Protection of Copper with Benzotriazole," *Plating and Surface Finishing*, Vol 73, June 1986, 99.



Copper. Corrosion of copper alloys that were galvanically coupled to titanium in boiling, deaerated 6% sodium chloride at 100 °C (212 °F). Source: T. Fukuzuka, K. Shimogori, H. Satoh, and F. Kamikubo, "Corrosion Problems and Countermeasures in MSF Desalination Plant Using Titanium Tube," Kobe Steel, Ltd., 1985.



Copper. Cycles to failure as a function of applied current in 3.5% sodium chloride for (90-10 cupronickel, CA 706). Source: D.P. Harvey, T.S. Sudarshan, *et al.*, "Corrosion Fatigue Behavior of 90/10 Copper-Nickel Cladding for Marine Structures," *Journal of Materials for Energy Systems*, Vol 7, Dec 1985, 272.



Iron. Corrosion rate (mdd) for iron, pure and alloyed, with stated percentages of sulfur, manganese, copper, phosphorus, carbon and silicon in acid sodium chloride solution. In three cases, the change in corrosion potential is also shown. Source: G. Wranglen, *An Introduction to Corrosion and Protection of Metals*, Chapman Hall, New York, 1985, 74.

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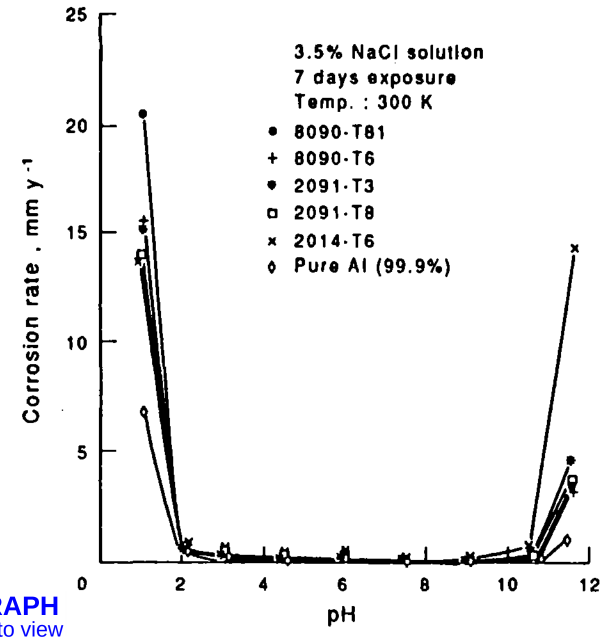

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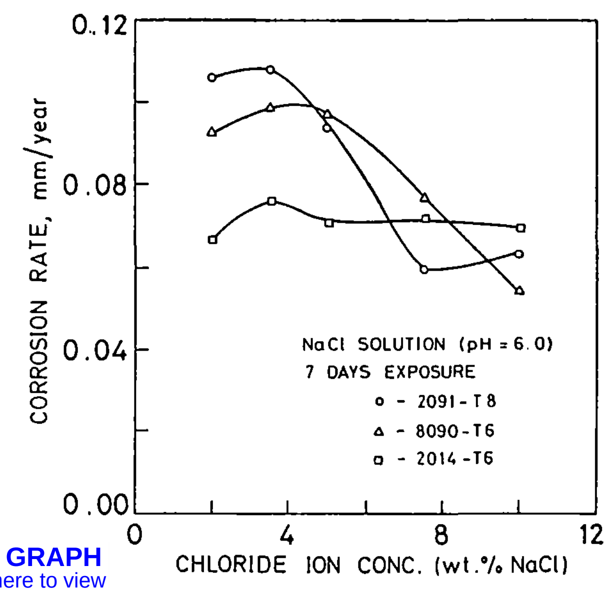
Various alloys. The dependence of corrosion rate on pH value for different alloys in 3.5% NaCl solution. Ref. 194



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Various alloys. Corrosion rate-chloride ion concentration curves for various alloys in 3.5% NaCl solution. Ref. 247

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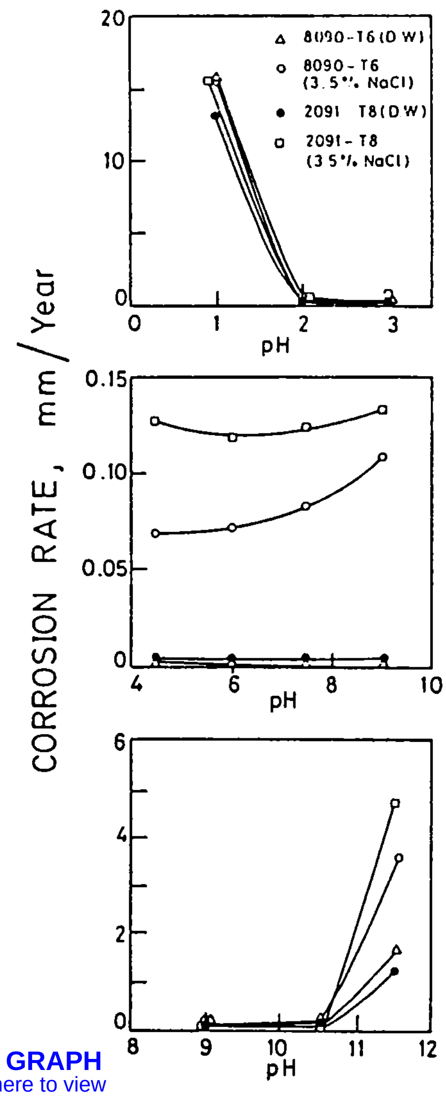

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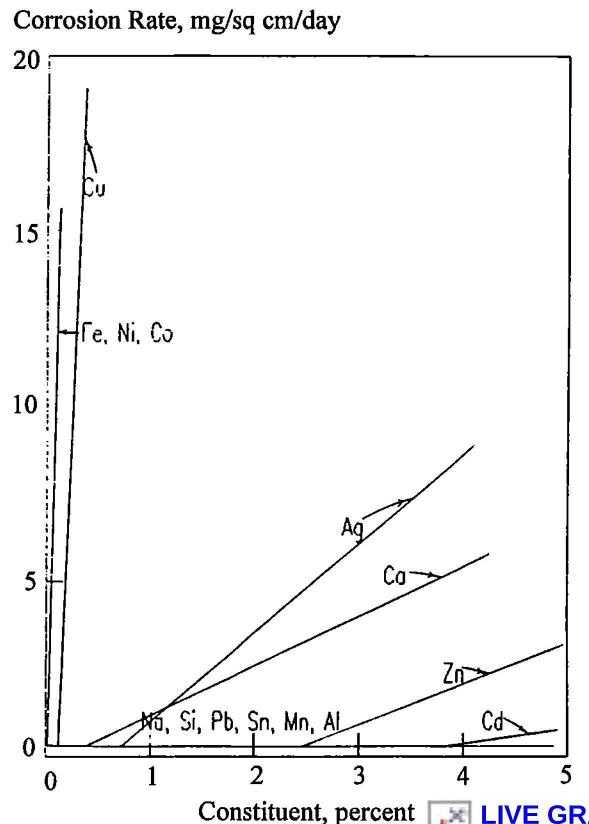
Various alloys. Corrosion rate-pH curves for various alloys in 3.5% NaCl and in distilled water. Ref. 247



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Magnesium alloys. Corrosion of magnesium binary alloys (alternate immersion in 3% NaCl). Ref. 279

Sodium Chlorite

Sodium chlorite, $NaClO_2$, is an explosive, white, mildly hygroscopic, water-soluble powder that decomposes at 175 °C. Used as an analytical reagent and oxidizing agent.

Corrosion Behavior of Various Metals and Alloys in Sodium Chlorite

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	5	20 (68)	...	Questionable	Pitting	253
301	S30100	...	...	5	Boiling	...	Poor	Pitting	253
302	S30200	...	...	5	20 (68)	...	Questionable	Pitting	253
302	S30200	...	...	5	Boiling	...	Poor	Pitting	253
303	S30300	...	...	5	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	5	Boiling	...	Poor	Pitting	253
304	S30400	...	...	5	20 (68)	...	Questionable	Pitting	253
304	S30400	...	...	5	Boiling	...	Poor	Pitting	253
304L	S30403	...	...	5	20 (68)	...	Questionable	Pitting	253
304L	S30403	...	...	5	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	5	20 (68)	...	Questionable	Pitting	253
304LN	S30453	...	...	5	Boiling	...	Poor	Pitting	253
316	S31600	...	...	5	20 (68)	...	Questionable	Pitting	253
316	S31600	...	...	5	Boiling	...	Questionable	Pitting	253
316F	S31620	...	...	5	20 (68)	...	Questionable	Pitting	253
316F	S31620	...	...	5	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	5	20 (68)	...	Questionable	Pitting	253
316L	S31603	...	...	5	Boiling	...	Questionable	Pitting	253
316LN	S31653	...	...	5	20 (68)	...	Questionable	Pitting	253
316LN	S31653	...	...	5	Boiling	...	Questionable	Pitting	253
316Ti	S31635	...	...	5	20 (68)	...	Questionable	Pitting	253
316Ti	S31635	...	...	5	Boiling	...	Questionable	Pitting	253
317L	S31703	...	...	5	20 (68)	...	Questionable	Pitting	253
317L	S31703	...	...	5	Boiling	...	Questionable	Pitting	253
317LN	S31725	...	...	5	20 (68)	...	Questionable	Pitting	253
317LN	S31725	...	...	5	Boiling	...	Questionable	Pitting	253
321	S32100	...	...	5	20 (68)	...	Questionable	Pitting	253
321	S32100	...	...	5	Boiling	...	Poor	Pitting	253
329	S32900	...	...	5	20 (68)	...	Questionable	Pitting	253
329	S32900	...	...	5	Boiling	...	Questionable	Pitting	253
347	S34700	...	...	5	20 (68)	...	Questionable	Pitting	253
347	S34700	...	...	5	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	5	20 (68)	...	Questionable	Pitting	253
F51	S31803	...	...	5	Boiling	...	Questionable	Pitting	253

Sodium Fluoride

Sodium fluoride, NaF, also known as villiaumite, is a white, poisonous, crystalline powder that melts at 980 °C (1796 °F). Sodium fluoride is formed by the reaction of sodium carbonate and hydrofluoric acid. It is soluble in water and is used in dentistry to prevent tooth decay. Sodium fluoride is used in agriculture as a fungicide and an insecticide, in the preparation of ceramic enamels and fluxes, and as a preservative for food, wood, and adhesives.

Material Summaries

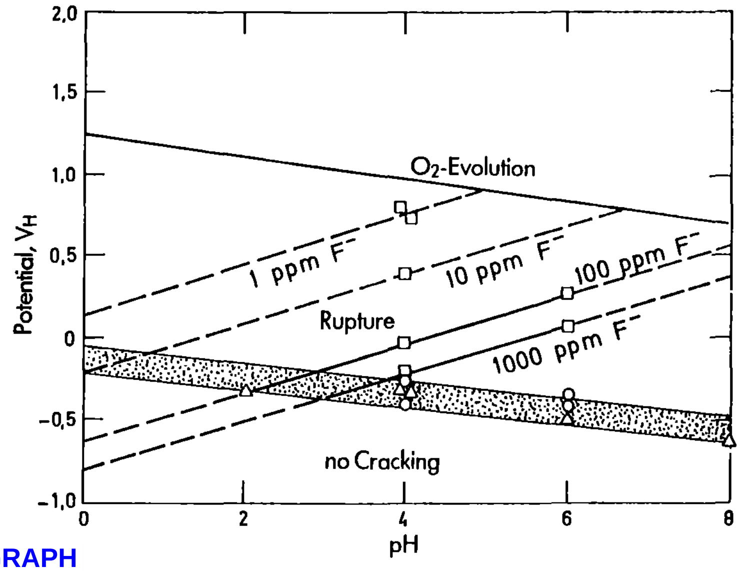
The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. During laboratory tests at ambient temperature and 100% relative humidity, aluminum alloy 3003 was attacked by solid sodium fluoride. Other tests disclosed that aqueous solutions (0.1 to 4%) of sodium fluoride attacked aluminum alloy 1100 at a moderate (0.25 mm/yr, or 10 mils/yr) rate that varied with concentration.

Zirconium. Although zirconium has good resistance in sodium fluoride at low temperatures, resistance decreases rapidly with increasing temperature.

Corrosion Behavior of Various Metals and Alloys in Sodium Fluoride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
7075-T6	A97075	...	...	.04	22 (72)	14 d	.03 (1.2)	...	257
7075-T6	A97075	...	...	.41	22 (72)	14 d	.15 (5.9)	...	257
7075-T6	A97075	...	...	4.1	22 (72)	14 d	.006 (0.2)	...	257
Miscellaneous									
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Magnesium	...	...	Specimen size, 75 × 25 × 1.5 mm (3 × 1 × 0.06 in.); surface preparation, HNO_3 pickling; volume of testing solution, 100 ml. Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	...	...	12
Nickel and alloys									
Alloy 825	N08825	...	Metal processing; no aeration; no agitation. Plus aluminum fluoride, sodium sulfate, sodium carbonate, sodium bicarbonate, air water, aluminum oxide, pH 9	...	30 (87)	69 d	.003 (0.1) max	...	89
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	0.008 (0.32)	...	90
Titanium	...	...	pH 10	1	Boiling	...	0.001 (0.04)	...	90
Titanium	...	...	pH 7	1	Boiling	...	0.001 (0.04)	...	90
Titanium	...	...	pH 7	1	204 (399)	...	0.000 (0.000)	...	90
Titanium, grade 12	R53400	...	pH 7	1	Boiling	...	0.001 (0.039)	...	33
Titanium, grade 7	R52400	...	pH 7	1	Boiling	...	0.002 (0.07)	...	33
Zirconium	R60702	...	...	Saturated	28 (82)	...	Resistant	...	15
Zirconium	R60702	...	...	Saturated	90 (195)	...	1.3 (50) min	...	15
Stainless steels									
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
317	S31700	...	Metal processing; no aeration; no agitation. Plus aluminum fluoride, sodium sulfate, sodium carbonate, sodium bicarbonate, air, water, aluminum oxide, pH 9	...	30 (87)	69 d	.003 (0.1) max	...	89
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Good	...	121
Carpenter 20	...	...	Metal processing; no aeration; no agitation. Plus aluminum fluoride, sodium sulfate, sodium carbonate, sodium bicarbonate, air water, aluminum oxide, pH 9	...	30 (87)	69 d	.003 (0.1) max	...	89
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253



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□: SCC potential; ○: corrosion potential; Δ : maximum corrosion potential in open circuit

304 stainless steel. Influence of potential and pH on the intercrystalline stress corrosion cracking of sensitized steel AISI 304 in NaF solutions at 65 °C (150 °F). Ref. 257

Sodium Hydrogen Phosphate

Sodium hydrogen phosphate, $NaH_2PO_4 \cdot H_2O$, is hygroscopic, transparent, water-soluble crystals. Used as a purgative, reagent, and buffer.

Corrosion Behavior of Various Metals and Alloys in Sodium Hydrogen Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydrogen Phosphate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Sodium Hydroxide

Sodium hydroxide, NaOH, also referred to as caustic soda or sodium hydrate (and formerly known as lye), is a white, massive, deliquescent crystalline solid that is soluble in water, alcohol, and glycerol. It melts at 318 °C (606 °F) and is the most widely used and available alkaline chemical. Most sodium hydroxide is produced as a coproduct of chlorine through the use of electrolytic cells; the cells are of the diaphragm, mercury, or membrane type. Some sodium hydroxide is marked as produced in the cells; most is evaporated and sold as 50 and 73% solutions or as anhydrous beads. Most caustic end uses require solutions of relatively low concentrations. Caustic soda is used as an analytical reagent and chemical intermediate, in scouring and cleaning baths, in rubber reclaiming and petroleum refining, in quenching baths for heat treating of steel, in cutting and soluble oils, in soaps and detergents, and in a wide variety of other applications.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Cast Irons. Unalloyed cast irons exhibit generally good resistance to alkali solutions (caustic solutions) such as sodium hydroxide, with the resistance being approximately equivalent to that of steel. These cast irons are not attacked by dilute alkalis at any temperature. Hot alkalis at concentrations exceeding 30% attack unalloyed iron. Temperatures should not exceed 80 °C (175 °F) for concentrations up to 70% if corrosion rates of less than 0.25 mm/yr (10 mils/yr) are desired. Ductile and gray iron exhibit about equal resistance to alkalis; however, ductile iron is susceptible to cracking in highly alkaline solutions, but gray iron is not. Alloying with 3 to 5% nickel substantially improves the resistance of cast irons to alkalis. High-nickel austenitic cast irons offer even better resistance to alkalis than unalloyed or low-nickel cast irons.

High-silicon cast irons exhibit good resistance to relatively dilute solutions of sodium hydroxide at moderate temperatures, but should not be applied for more concentrated conditions at elevated temperatures. High-silicon cast irons are usually economical over unalloyed and nickel cast irons in alkaline solutions only when other corrosives are involved for which the lesser alloys are unsuitable. High-chromium cast irons have inferior resistance to alkaline solutions and are generally not recommended for alkaline service.

Austenitic cast irons (Ni-Resist types) show superior resistance to caustic solutions up to 70% concentration and approaching boiling temperatures; corrosion rates are generally less than 0.25 mm/yr (10 mils/yr). Nickel-containing cast irons generally benefit by additional nickel alloying as long as sulfur or sulfur compounds are not present.

Stress-corrosion cracking is not a problem for cast irons.

Carbon and Alloy Steels. The possibilities of product contamination and stress-corrosion cracking (often called caustic embrittlement) are primary restrictions to the use of iron and steel in caustic service. These problems limit applications, yet low-carbon steel remains the most frequently used material. It is effective in caustic solutions of up to 50% concentration and at temperatures up to 90 °C (190 °F).

Effective use is made of bare steel tanks storing 50% caustic temperatures from ambient to 65 °C (150 °F). Iron contamination is frequently a concern because many caustic applications must limit the presence of iron to only a few parts per million. Where iron contamination of the product is of concern, spray-applied neoprene latex or phenolic-expoxy linings are used. If iron contamination is not a problem, the next limiting factor is stress-corrosion cracking.

Stainless Steels. All stainless steels resist general corrosion by all concentrations of sodium hydroxide up to about 65 °C (150 °F). Types 304 and 316 stainless steels exhibit low rates of general corrosion in boiling sodium hydroxide up to nearly 20% concentration. Stress-corrosion cracking of these grades can occur at about 100 °C (212 °F). Good resistance to general corrosion and stress-corrosion cracking in 50% sodium hydroxide at 135 °C (275 °F) is provided by E-Brite and 7-Mo stainless steels.

Although the austenitic stainless steels crack readily in neutral and acid chlorides above 60 °C (140 °F), the effect of chlorides in an alkaline solution seems to be nil. As long as the solution remains alkaline, the mode of stress cracking is that of caustic embrittlement and continues to occur only in a limited range. A solution of 0.5 g/L sodium hydroxide with a

pH of 12 is sufficiently alkaline. The concern for chloride contaminations is caustic when using stainless steel equipment is not well founded.

More important concerns are those extraneous to the caustic solution. Failures resulting from such factors as external exposure, faulty insulation, contaminated test water, and improper cleaning and storage have produced more problems than handling caustic.

Because chloride pitting and/or chloride stress cracking are often primary concerns, alloy selection should consider relative performance in these areas. Although types 304 and 316 stainless steel perform comparably in caustic and in standard stress-cracking tests, type 316 shows improved overall performance because of its pitting resistance. The role of dissolved oxygen may be significant in this effect. In addition, the low-carbon grades perform marginally better because of their resistance to sensitization. This suggests that type 316L (molybdenum-containing, low-carbon type 316) should be used unless significant controls are to be placed on the total exposure of the equipment.

Applications of stainless steel for caustic service include piping, valves, pumps, and equipment. Transfer piping applications are quite common. Problems rarely occur whenever 10 to 20% solutions are involved, because clean-out and freezing considerations are minimal.

Cast stainless pumps and valves have performed very well in caustic applications. The nature of cast surfaces minimizes stress-corrosion cracking problems, and castings are usually acceptable in situations considerably beyond the capabilities of wrought products. Corrosion rates are similar to those of the wrought products.

One other practical application of stainless steel in caustic service is in evaporation processes, in which high-purity alloy 26-1 (a low-carbon version of type 446 stainless steel containing niobium and molybdenum) heat-exchanger tubing has been used. Some high-temperature applications have proven effective where corrosion rates on nickel are excessive. This is probably due to the presence of hypochlorite or chlorate contaminants. The debate between nickel and ferrous alloys continues, yet both materials have shown satisfactory performance. The 26-1 alloy is useful up to 175 °C (350 °F), depending on the caustic, chloride, and contaminant concentrations. When 26-1 is attacked, the normal failure mode seems to be intergranular. At this time, there are no specific criteria to provide recommendations regarding the use of ferritic stainless steel. There probably are suitable applications for the new ferritic and duplex steels; however, little testing has been completed.

Aluminum. Aluminum alloys exhibited poor resistance to sodium hydroxide solutions in laboratory tests at all concentrations and all temperatures. Additions of inhibitors, such as potassium dichromate, ammonium metavanadate, or ammonium persulfate, to dilute solutions of sodium hydroxide have repressed corrosion.

Copper. Copper and some copper-base alloys (aluminum bronzes and copper-nickel alloys) are generally suitable for service in sodium hydroxide. Higher nickel content in copper-nickel alloys indicates better resistance. Alloy 70-30 (CDA 71500) has been used where copper contamination can be tolerated. Zinc-containing brasses and bronzes are not suitable for sodium hydroxide service.

Nickel. Nickel and nickel-base alloys are used extensively in sodium hydroxide service. Their very low corrosion rates also ensure low metal ion contamination. Nickel has the lowest corrosion rates, even in molten anhydrous sodium hydroxide at temperatures up to 540 °C (1000 °F) and is essentially immune to caustic stress-corrosion cracking.

A major use for Nickel 200 is in the production of sodium hydroxide. Nickel 200 exhibits outstanding corrosion resistance to sodium hydroxide at concentrations up to anhydrous at boiling or molten temperatures. Caustic soda is normally produced at 11 to 15% concentration and further concentrated by evaporation to 50% or higher. As sodium hydroxide concentration and temperature increase during the evaporation process or during other chemical-processing conditions, the corrosivity increases dramatically. Similarly, increasing the nickel content of nickel-base alloys produces increasing resistance to general corrosion and stress-corrosion cracking in caustic. Thus, a number of nickel-base alloys can be used for handling sodium hydroxide, depending on solution concentration and temperature.

At temperatures above 315 °C (600 °F), Nickel 200 is replaced by Nickel 201 because of its low carbon content. This material was specifically designed to avoid potential intergranular corrosion, which may occur in Nickel 200 (0.15% carbon maximum). In areas of high stress, this type of attack has resulted in cracking after intergranular corrosion, but is mechanically driven.

In some caustic applications where higher strength or resistance to other corrodents is required, Monel 400, Inconel 600, Hastelloy C-276, and other nickel alloys are used. These alloys are highly resistant to general corrosion and stress-corrosion cracking, but can be attacked at high caustic concentrations and temperatures. In the handling of brines in sodium hydroxide production as well as the commercial production of salt, Monel 400 has performed well in a variety of components, such as heat exchangers, vacuum pans, heater tubes, rotary dryers, and transfer piping. Inconel 600 and Incoloy 800 have been used extensively in nuclear steam generator service at about 300 °C (570 °F). In this service, resistance to caustic, which can be formed and concentrated at tube sheets, is of concern. The higher chromium alloy Inconel 690 is more resistant to stress-corrosion cracking under some conditions.

Niobium. In ambient aqueous alkaline solutions, niobium has corrosion rates of less than 0.025 mm/yr (1 mil/yr). At higher temperatures, even though the corrosion rate does not seem excessive, niobium is embrittled even at low concentrations (5%) of sodium hydroxide.

Silver. Although it is attacked by most fused bisulfates, cyanides, halides, phosphates, and peroxides, silver is not attacked by sodium hydroxide at temperatures below 500 °C (930 °F).

Tantalum. Sodium hydroxide solutions do not dissolve tantalum, but tend to destroy the metal by formation of successive layers of surface scale. The rate of the destruction increases with concentration and temperature. Damage to tantalum equipment has been experienced unexpectedly when strong alkaline solutions have been used during cleaning and maintenance.

In a study using change in electrical resistivity to measure corrosion rates, tantalum wire totally immersed in 10% sodium hydroxide solution at room temperature for 210 days corroded at the rate of 0.24 μm/yr. A similar rate occurred in 10% sodium hydroxide at 100 °C (212 °F). In the latter case, there was some local effect at the points where the wire left the solution and entered submerged rubber stoppers in the sides of the corrosion vessel; this accounted for most of the weight loss.

In test conducted on unalloyed tantalum and a Ta-10W alloy in 5% sodium hydroxide solution at 100 °C (212 °F), both metals suffered considerable weight losses, and the difference, if any, between their corrosion rates was small. In this study, the sodium hydroxide corrosion test was conducted because tantalum is known to be susceptible to caustic embrittlement; therefore, it was desired to determine whether the Ta-

10W alloy suffered embrittlement also. Unalloyed tantalum showed approximately a 25% increase in yield strength and a 10% increase was attributed to a pickup of interstitial elements (oxygen, nitrogen, and hydrogen), although chemical analyses of the materials before and after exposure were not conducted. With the Ta-10W alloy, the exposure to 5% sodium hydroxide at 100 °C (212 °F) produced embrittlement, as evidenced by the premature fracture in the tensile test. Reportedly, such embrittlement was not evident on the sample of the Ta-10W alloy to which a platinum spot had been welded before the test.

Titanium. Titanium alloys are generally very resistant to alkaline media, including sodium hydroxide. Titanium exhibits low corrosion rates in sodium hydroxide at sub-boiling temperatures. However, significant increases in corrosion are noted as sodium hydroxide concentration increases at higher temperatures.

Although corrosion rates are relatively low in alkaline media, titanium alloys may experience excessive hydrogen pickup and eventual embrittlement under certain conditions. For alpha and near-alpha alloys, hydrogen embrittlement is possible when temperatures exceed 80 °C (175 °F) and pH is 12 or more. The presence of dissolved oxidizing species in hot caustic solutions, such as chlorate, hypochlorite, or nitrate compounds, can extend resistance to hydrogen uptake to somewhat higher temperatures.

Zirconium. Zirconium is very resistant to corrosion by molten sodium hydroxide at temperatures above 1000 °C (1830 °F). Zirconium U-bend specimens were tested in boiling concentrated sodium hydroxide. During the test period, the concentration changed from 50 to about 85%, and temperature increased from 150 to 300 °C (300 to 570 °F). The PTFE washers and tubes used to make the U-bends dissolved. However, the zirconium U-bend specimens remained ductile and did not show any cracks after 20 days. Zirconium is resistant to stress-corrosion cracking in sodium hydroxide.

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Pure Al	A91199	...	pH 10	...	30	80 d	.007	...	202
Pure Al	A91199	...	pH 10	...	60	80 d	0.16	...	202
Pure Al	A91199	...	pH 11	...	30	80 d	.009	...	202
Pure Al	A91199	...	pH 11	...	60	80 d	0.037	...	202
Pure Al	A91199	...	pH 12	...	30	80 d	.052	...	202
Pure Al	A91199	...	pH 8	...	30	80 d	.003	...	202
Pure Al	A91199	...	pH 8	...	60	80 d	.003	...	202
Pure Al	A91199	...	pH 9	...	30	80 d	.004	...	202
Pure Al	A91199	...	pH 9	...	60	80 d	.003	...	202
Carbon and alloy steels									
Carbon steel	G10100	...	...	...	...	100 d	.035 (1.4)	...	221
Carbon steel	G10100	...	...	...	...	100 d	.084 (3.3)	...	221
Carbon steel	G10100	...	...	...	...	100 d	.094 (3.7)	...	221
Carbon steel	G10100	...	...	...	...	100 d	1.448 (57)	...	221
Low-carbon steel	G10100	...	...	5-10	21 (70)	124 d	0.1 (4)	Slight pitting attack	112
Low-carbon steel	G10100	...	...	50	40 (100)	162 d	0.018 (0.7)	...	111
Low-carbon steel	G10100	...	...	50	55-75 (130-165)	30 d	0.2 (8)	...	112
Low-carbon steel	G10100	...	...	50	60 (135)	135 d	0.13 (5)	...	111
Low-carbon steel	G10100	...	Diaphragm cell	50	35-90 (95-190)	...	0.12 (4.7)	...	114
Low-carbon steel	G10100	...	Diaphragm cell	73	100-125 (212-260)	...	0.87 (34.2) min	...	114
Low-carbon steel	G10100	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl; slight attack under spacer	10	80 (180)	207 d	0.015 (0.6)	...	111
Low-carbon steel	G10100	...	First effect of a multi-effect evaporator	14	90 (190)	90 d	0.21 (8.2)	...	112
Low-carbon steel	G10100	...	Mercury cell	50	40-80 (100-180)	...	0.09 (3.4)	...	114
Low-carbon steel	G10100	...	Mercury cell	73	115 (240)	...	1.8 (71)	...	114
Low-carbon steel	G10100	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and Na_2NO_3	73	540 (1000)	2.5 d	12.7 (500)	...	114
Low-carbon steel	G10100	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.09 (3.7)	...	113
Mild steel	G10100	...	NaCl concentration unknown	72	121 (250)	29 d	0.102 (4)	...	112
Mild steel	G10100	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.127 (5)	...	112
Mild steel	G10100	...	NaCl concentration, 12%	10	88 (190)	29 d	0.127 (5)	...	112
Mild steel	G10100	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	1.169 (46)	...	112

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Mild steel	G10100	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.229 (9)	...	112
Steel	G10100	...	...	0.0 g/L	Room	22 d	0.05 (2)	...	117
Steel	G10100	...	...	0.001 g/L	Room	22 d	0.05 (2)	...	117
Steel	G10100	...	...	0.01 g/L	Room	22 d	0.05 (2)	...	117
Steel	G10100	...	...	1.0 g/L	Room	22 d	0.018 (0.7)	...	117
Steel	G10100	...	...	10 g/L	Room	22 d	Resistant	...	117
Steel	G10100	...	...	100 g/L	Room	22 d	0.0025 (0.1)	...	117
Steel	G10100	...	...	540 g/L	Room	22 d	Resistant	...	117
Steel	G10100	...	...	70-73	110 (230)	126 d	0.99 (39)	...	111
Steel	G10100	...	...	70-73	90-115 (190-240)	90 d	1.45 (57)	...	112
Steel	G10100	...	...	70-73	130 (265)	200 d	2 (80) min	...	113
Copper and alloys									
60-40 cupronickel	...	...	Diaphragm cell liquor-coupons in distributor box to settlers	11	Hot	25 d	0.012 (0.5)	...	112
60-40 cupronickel	...	...	Lab test	5	15-20 (59-68)	21 d	Resistant	...	112
70-30 cupronickel	C71500	...	...	50	55-75 (130-165)	30 d	0.013 (0.1)	...	112
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	...	73	105 (221)	118 d	0.03 (1.2)	...	112
70-30 cupronickel	C71500	...	Diaphragm cell liquor-coupons in distributor box to settlers	11	Hot	25 d	0.11 (4.3)	...	112
70-30 cupronickel	C71500	...	In anhydrous melt	100	400-410 (752-700)	1 d	1.77 (70)	...	112
70-30 cupronickel	C71500	...	In evaporator concentrating from 60% to anhydrous	60-100	150-260 (302-500)	2 d	0.533 (21)	...	112
70-30 cupronickel	C71500	...	In evaporator concentrating from 60-75%	60-75	150-175 (302-347)	0.5 d	0.11 (4.4)	...	112
70-30 cupronickel	C71500	...	In storage tank	50	65 (149)	30 d	Resistant	...	112
70-30 cupronickel	C71500	...	Lab test	5	15-20 (59-68)	21 d	Resistant	...	112
70-30 cupronickel	C71500	...	Velocity 1.8 ft/s. Salt saturated	50	95 (203)	67 d	0.02 (0.8)	...	112
80-20 cupronickel	C71000	...	In anhydrous melt	100	400-410 (752-770)	1 d	2.28 (90)	...	112
80-20 cupronickel	C71000	...	In evaporator concentrating from 60% to anhydrous	60-100	150-260 (302-500)	2 d	0.711 (28)	...	112
80-20 cupronickel	C71000	...	In evaporator concentrating from 60-75%	60-75	150-175 (302-347)	0.5 d	0.205 (8.1)	...	112
80-20 cupronickel	C71000	...	Lab test	5	15-20 (59-68)	21 d	Resistant	...	112
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	73	105 (221)	118 d	0.05 (2)	...	112
90-10 cupronickel	C70600	...	Velocity 1.8 ft/s. saturated	50	95 (203)	67 d	0.045 (1.8)	...	112
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	70-73	110 (230)	126 d	0.02 (0.9)	...	111
Aluminum bronze	...	...	...	70-73	120 (240)	180 d	0.15 (6.1)	...	113
Aluminum bronze	...	...	...	5	Room	...	0.09 (3.8)	...	116
Aluminum bronze	...	...	...	15	Room	...	1.02 (0.7)	...	116
Aluminum bronze	...	...	...	25	Room	...	0.008 (0.3)	...	116
Aluminum bronze	...	...	...	35	Room	...	0.01 (0.4)	...	116
Aluminum bronze	...	...	...	45	Room	...	0.005 (0.2)	...	116
Aluminum bronze	...	...	...	50	60 (135)	135 d	0.025 (1)	...	111
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	Lab test	50	150 (300)	...	0.08 (3)	...	113
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Copper	...	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.06 (2.3)	...	113

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper-nickel-zinc (75Cu-20Ni-5Zn)	...	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.013 (0.5)	...	113
Deoxidized copper	C12000	...	...	5	Room	...	0.09 (3.4)	...	116
Deoxidized copper	C12000	...	...	15	Room	...	0.01 (0.3)	...	116
Deoxidized copper	C12000	...	...	25	Room	...	0.01 (0.3)	...	116
Deoxidized copper	C12000	...	...	35	Room	...	0.025 (1)	...	116
Deoxidized copper	C12000	...	...	45	Room	...	0.005 (0.2)	...	116
Deoxidized copper	C12000	...	Lab test	50	150 (300)	...	0.14 (5.5)	...	113
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Iron and alloys									
3% nickel-iron	...	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	1.8 (71)	...	115
Cast iron	F10001	...	...	50	55-75 (130-165)	30 d	0.27 (10.5)	...	112
Cast iron	F10001	...	0% nickel	50-65	...	81 d	1.9 (73)	...	112
Cast iron	F10001	...	0% nickel	50-65	...	81 d	2.2 (86)	...	112
Cast iron	F10001	...	0% nickel	50-65	...	81 d	2.3 (91)	...	112
Cast iron	F10001	...	15% nickel	50-65	...	81 d	0.8 (30)	...	112
Cast iron	F10001	...	20% nickel plus 2% chromium	50-65	...	81 d	0.15 (6)	...	112
Cast iron	F10001	...	20% nickel.	50-65	...	81 d	0.08 (3.3)	...	112
Cast iron	F10001	...	3.5% nickel	50-65	...	81 d	1.2 (47)	...	112
Cast iron	F10001	...	30% nickel	50-65	...	81 d	0.01 (0.4)	...	112
Cast iron	F10001	...	5% nickel	50-65	...	81 d	1.24 (49)	...	112
Cast iron	F10001	...	Diaphragm cell	50	35-90 (95-190)	...	0.11 (4.2)	...	114
Cast iron	F10001	...	Diaphragm cell	73	100-125 (212-260)	...	1.1 (42)	...	114
Cast iron	F10001	...	First effect of a multi-effect evaporator	14	90 (190)	90 d	0.21 (8.2)	...	112
Cast iron	F10001	...	Lab test. NaOH conentrated to anhydrous	75	480 (900)	...	3.3 (130)	...	114
Cast iron	F10001	...	Mercury cell	50	40-80 (100-180)	...	0.08 (3.3)	...	114
Cast iron	F10001	...	Mercury cell	73	115 (240)	...	2.1 (82)	...	114
Cast iron	F10001	...	NaCl concentration unknown	72	121 (250)	29 d	0.4 (16)	...	112
Cast iron	F10001	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.152 (6)	...	112
Cast iron	F10001	...	NaCl concentration, 12%	10	88 (190)	29 d	0.102 (4)	...	112
Cast iron	F10001	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	1.245 (49)	...	112
Cast iron	F10001	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.254 (2)	...	112
Cast iron	F10001	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and Na_2NO_3	73	540 (1000)	2.5 d	5.3 (210)	...	114
Cast iron	F10001	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.18 (7)	...	113
Ductile austenitic cast iron	F43000	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	12 (470)	Pit depth 1.5 mm (60 mils)	115
Ductile cast iron	F30000	...	Diaphragm cell	50	35-90 (95-190)	...	0.1 (3.9)	...	114
Ductile cast iron	F30000	...	Diaphragm cell	73	100-125 (212-260)	...	1.7 (66)	...	114

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ductile cast iron	F30000	...	Mercury cell	50	40-80 (100-180)	...	0.06 (2.4)	...	114
Ductile cast iron	F30000	...	Mercury cell	73	115 (240)	...	2.6 (103)	...	114
Ductile cast iron	F30000	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	5.3 (207)	...	115
Gray cast iron	F10001	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	3.4 (135) max	Pit depth 0.13 mm (5 mils)	115
Ni-Resist I	F41000	...	...	50	55-75 (130-165)	30 h	0.05 (2)	...	112
Ni-Resist I	F41000	...	First effect of a multi-effect evaporator	14	90 (190)	90 d	0.07 (2.9)	...	112
Ni-Resist type 1	F41000	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	16 (630)	Pit depth 1.5 mm (60 mils)	115
Ni-Resist type 2	F41002	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	24 (950)	Pit depth 1.8 mm (70 mils)	115
Ni-Resist type 3	F41004	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	2.2 (87)	...	115
Ni-Resist type 4	F41005	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	14 (530)	Pit depth 1.0 mm (40 mils)	115
Ni-Resist, type 2	F41002	...	Lab test. NaOH concentrated to anhydrous	75	480 (900)	...	3.8 (150)	...	114
Ni-Resist, type 2	F41002	...	Lab tests	20	127 (293)	15 h	2.388 (94)	...	112
Ni-Resist, type 2	F41002	...	Lab tests	40	127 (293)	15 h	0.152 (6)	...	112
Ni-Resist, type 2	F41002	...	Lab tests	60	127 (293)	15 h	0.432 (17)	...	112
Ni-Resist, type 2	F41002	...	Lab tests	80	127 (293)	15 h	0.711 (28)	...	112
Ni-Resist, type 3	F41004	...	Diaphragm cell	50	35-90 (95-190)	...	0.0064 (0.25)	...	114
Ni-Resist, type 3	F41004	...	Diaphragm cell	73	100-125 (212-260)	...	0.094 (3.7)	...	114
Ni-Resist, type 3	F41004	...	Lab test. NaOH concentrated to anhydrous	73	480 (900)	...	3.3 (130)	...	114
Ni-Resist, type 3	F41004	...	Mercury cell	50	40-80 (100-180)	...	0.0025 (0.1)	...	114
Ni-Resist, type 3	F41004	...	Mercury cell	73	115 (240)	...	0.03 (1.2)	...	114
Ni-Resist, type 3	F41004	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.102 (0.4)	...	112
Ni-Resist, type 3	F41004	...	NaCl concentration, 12%	10	88 (190)	29 d	0.005 (0.2)	...	112
Ni-Resist, type 3	F41004	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	0.076 (3)	...	112
Ni-Resist, type 3	F41004	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.025 (1)	...	112
Ni-Resist, type 3	F41004	...	NaCl concentration, unkown	72	121 (250)	29 d	0.127 (5)	...	112
White iron	F45000	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	3.8 (151)	Pit depth 0.5 mm (20 mils)	115
Miscellaneous									
Lead	L50045	...	...	0-30	26 (79)	...	0.5 (20) max	...	95
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Platinum	P04995	...	...	90 max	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	350 (660)	...	0.05 (2) max	...	5
Silver	P07010	...	...	95 max	Boiling	...	0.05 (2) max	...	9
Silver	P07010	...	Lab test, NaOH concentrated to anhydrous	75	480 (900)	...	0.13 (5.3)	...	114
Silver	P07010	...	Melt	...	500 (930)	...	0.05 (2) max	...	9
Tin	...	...	...	0.005	60 (140)	...	0.21 (8.3)	...	75
Tin	...	...	...	0.02	60 (140)	...	0.24 (9.4)	...	75
Tin	...	...	...	0.05	60 (140)	...	0.21 (8.3)	...	75
Tin	...	...	...	0.10	60 (140)	...	0.20 (7.9)	...	75
Tin	...	...	...	0.15	60 (140)	...	0.20 (7.9)	...	75
Tin	...	...	...	0.20	60 (140)	...	0.21 (8.3)	...	75
Tin	...	...	...	0.25	60 (140)	...	0.24 (9.4)	...	75

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
WC-2TaC-3TiC	...	...	...	5	50 (120)	72 h	0.003 (0.1)	...	147
WC-2TaC-3TiC	...	...	...	10	50 (120)	72 h	0.003 (0.1)	...	147
WC-5TaC	...	...	...	5	50 (120)	72 h	0.003 (0.1)	...	147
WC-5TaC	...	...	...	10	50 (120)	72 h	0.003 (0.1)	...	147
WC-6Co	...	...	...	5	50 (120)	72 h	0.003 (0.1)	...	147
WC-6Co	...	...	...	10	50 (120)	72 h	0.003 (0.1)	...	147
WC-8Ni-2Mo-3Cr	...	...	...	5	50 (120)	72 h	0.003 (0.1) max	...	147
WC-8Ni-2Mo-3Cr	...	...	...	10	50 (120)	72 h	0.003 (0.1) max	...	147
WC-9Co	...	...	...	5	50 (120)	72 h	0.003 (0.1)	...	147
WC-9Co	...	...	...	10	50 (120)	72 h	0.003 (0.1)	...	147
Nickel and alloys									
Alloy 825	N08825	...	Chemical distillation; no aeration; slight to moderate agitation. Plus 2% chlorine-saturated monochlorotoluene, approx. 2% hydrochloric acid, batch still	15	100 (212)	33 d	0.45 (18)	Severe pitting; crevice attack	89
Alloy 825	N08825	...	Lab test; Rapid agitation Plus occasionally some sulfuric acid	3-10	87 (190)	300 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	No aeration; Rapid agitation Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Rapid agitation	74	129 (265)	88 d	0.01 (0.3)	...	89
Alloy 825	N08825	...	Slight to moderate aeration; Rapid agitation Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Slight to moderate aeration; rapid agitation. Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
Cabot alloy No. 625	N06625	...	...	10	66 (151)	96 h	Resistant	...	67
Cabot alloy No. 625	N06625	...	...	10	93 (199)	96 h	Resistant	...	67
Cabot alloy No. 625	N06625	...	...	10	Boiling	96 h	0.003 (0.1) max	...	67
Cabot alloy No. 625	N06625	...	...	30	66 (151)	96 h	Resistant	...	67
Cabot alloy No. 625	N06625	...	...	30	93 (199)	96 h	Resistant	...	67
Cabot alloy No. 625	N06625	...	...	30	Boiling	96 h	Resistant	...	67
Cabot alloy No. 625	N06625	...	...	50	66 (151)	96 h	0.003 (0.1) max	...	67
Cabot alloy No. 625	N06625	...	...	50	93 (199)	96 h	0.01 (0.4)	...	67
Cabot alloy No. 625	N06625	...	...	50	Boiling	96 h	0.06 (2.4)	...	67
Duranickel alloy 301	...	...	Molten	...	400 (750)	...	0.04 (1.7)	...	112
Duranickel alloy 301	...	...	Molten	...	500 (932)	...	0.08 (3.2)	...	112
Duranickel alloy 301	...	...	Molten	...	580 (1076)	...	0.26 (10)	...	112
Duranickel alloy 301	...	...	Molten	...	680 (1256)	...	1.0 (41)	...	112
Electroless nickel	...	1-4% Phosphorus	...	...	...	100 d	.0003 (0.01)	...	221
Electroless nickel	...	1-4% Phosphorus	...	...	...	100 d	.0053 (0.20)	...	221
Electroless nickel	...	1-4% Phosphorus	...	...	...	100 d	.0053 (0.20)	...	221
Electroless nickel	...	1-4% Phosphorus	...	...	...	100 d	.0061 (0.24)	...	221
Electroless nickel	...	1-4% Phosphorus	...	...	...	100 d	.0023 (0.09)	...	221
Electroless nickel	...	5-8% Phosphorus	...	35	93 (199)	100 d	.018 (0.71)	...	221
Electroless nickel	...	5-8% Phosphorus	...	50	93 (199)	100 d	.0048 (0.19)	...	221
Electroless nickel	...	5-8% Phosphorus	...	73	120 (248)	100 d	.0074 (0.29)	...	221

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Electroless nickel	...	...	...	...	93 (199)	100 d	.0132 (0.52)	...	221
Electroless nickel	...	...	...	...	93 (199)	100 d	.533 (21.0)	...	221
Electroless nickel	...	5-8% Phosphorus	Plus 5% NaCl	45	40 (104)	100 d	.003 (0.01)	...	221
Electroless nickel	...	5-8% Phosphorus	Plus 5% NaCl	45	140 (284)	100 d	.012 (0.47)	...	221
Electroless nickel	...	9-12% Phosphorus	Plus 5% NaCl	...	40 (104)	100 d	.0008 (0.03)	...	221
Hastelloy alloy C	...	...	Molten	...	500 (932)	...	250 (100)	...	112
Hastelloy alloy D	...	...	Molten	...	400 (750)	...	0.02 (0.7)	...	112
Hastelloy alloy D	...	...	Molten	...	500 (932)	...	0.06 (2.2)	...	112
Hastelloy alloy D	...	...	Molten	...	580 (1076)	...	0.25 (9.9)	...	112
Incoloy 800	N08800	...	Diaphragm cell	50	35-90 (95-190)	...	0.003 (0.1) max	...	114
Incoloy 800	N08800	...	Diaphragm cell	73	100-125 (212-260)	...	0.04 (1.6)	...	114
Incoloy 800	N08800	...	Mercury cell	50	40-80 (100-180)	...	0.003 (0.1) max	...	114
Incoloy 800	N08800	...	Mercury cell	73	115 (240)	...	0.008 (0.3)	...	114
Incoloy 800	N08800	...	NaCl concentration unknown	72	121 (250)	29 d	0.003 (0.1) max	...	112
Incoloy 800	N08800	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.003 (0.1) max	...	112
Incoloy 800	N08800	...	NaCl concentration, 12%	10	88 (190)	29 d	0.003 (0.1) max	...	112
Incoloy 800	N08800	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	0.015 (0.6)	...	112
Incoloy 800	N08800	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.005 (0.2)	...	112
Incoloy Alloy 800	N08800	...	...	...	...	7 d	.011 (.43)	...	217
Incoloy alloy 800	N08800	...	...	...	...	7 d	.397 (15.6)	...	217
Incoloy alloy 800	N08800	...	Plus 6.7% NaCl	...	...	7 d	.283 (11.2)	...	217
Incoloy alloy 800	N08800	...	Plus 8% NaCl	...	...	7 d	.013 (.51)	...	217
Inconel 600	N06600	...	...	5-10	21 (70)	124 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	...	50	40 (100)	162 d	0.003 (0.1) max	...	111
Inconel 600	N06600	...	...	50	60 (135)	135 d	0.003 (0.1) max	...	111
Inconel 600	N06600	...	...	50	55-75 (130-165)	30 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	...	70-73	110 (230)	126 d	0.0025 (0.1)	...	111
Inconel 600	N06600	...	...	70-73	90-115 (190-240)	90 d	0.008 (0.3)	...	112
Inconel 600	N06600	...	...	70-73	120 (240)	180 d	0.005 (0.2)	...	113
Inconel 600	N06600	...	...	70-73	130 (265)	200 d	0.025 (1)	...	113
Inconel 600	N06600	...	Concentration in caustic evaporator. Concentration: 60 to nearly anhydrous. Aeration: none. Agitation: none	...	150-260 (302-500)	2 d	...	...	112
Inconel 600	N06600	...	Coupons in railroad tank car. Aeration: not specified. Agitation: by movement of tank car	74	130 (266)	9 d	...	...	112
Inconel 600	N06600	...	Diaphragm cell	50	35-90 (95-190)	...	0.003 (0.1) max	...	114
Inconel 600	N06600	...	Diaphragm cell	73	100-125 (212-260)	...	0.005 (0.2)	...	114
Inconel 600	N06600	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl	10	80 (180)	207 d	Resistant	...	111
Inconel 600	N06600	...	First effect of a multi-effect evaporator	14	90 (190)	90 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Lab test on tubing; average of four coupons. Aertation: none. Agitation: none	50	150 (302)	14 d	0.0064 (0.25)	...	112
Inconel 600	N06600	...	Mercury cell	50	40-80 (100-180)	...	0.003 (0.1) max	...	114
Inconel 600	N06600	...	Mercury cell	73	115 (240)	...	0.005 (0.2)	...	114
Inconel 600	N06600	...	Molten	90	400 (750)	...	0.03 (1.1)	...	112
Inconel 600	N06600	...	Molten	...	500 (932)	...	0.06 (2.4)	...	112
Inconel 600	N06600	...	Molten	90	580 (1076)	...	0.13 (5.1)	...	112
Inconel 600	N06600	...	Molten	...	680 (1256)	...	1.7 (66)	...	112
Inconel 600	N06600	...	NaCl concentration 12%	10	88 (190)	29 d	0.003 (0.1) max	...	112

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 600	N06600	...	NaCl concentration unknown	72	121 (250)	29 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	0.0127 (0.5)	...	112
Inconel 600	N06600	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and Na_2NO_3	73	540 (1000)	2.5 d	49 (1930)	...	114
Inconel 600	N06600	...	Single-effect evaporator. Rates are average of three tests. Aeration: none. Agitation: none	30-50	81 (178)	16 d	...	...	112
Inconel 600	N06600	...	Storage tank between evaporator and finishing pots. Ammonia soda process. Aeration: not specified. Agitation: due to filling tank	75	135 (271)	35 d	0.03 (1.3)	...	112
Inconel 600	N06600	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	49-51	55-75 (131-167)	30 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	73	104-116 (244-251)	126 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	22	50-60 (120-140)	133 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	73	() 100-120 (212-248)	52 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	Storage tank in which air was bubbled through from bottom. Aeration: extensive. Agitation: mild	34	65 (150)	37 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Storage tank. Aeration: extensive. Agitation: due to filling tank	5-10	21-32 (70-90)	124 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	Storage tank. Aeration: none. Agitation: due to filling tank.	72-73	116 (273)	183 d	0.01 (0.4)	...	112
Inconel 600	N06600	...	Storage tank. Aeration: none. Agitation: due to filling tank.	72	121 (282)	119 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	Storage tank. Aertation: none. Agitation: due to filling tank	50	55-61 (131-142)	135 d	0.003 (0.1) max	...	112
Inconel 600	N06600	...	Test coupons removed, cleaned and dried each day for 30 d. Aeration: none. Agitation: none	0.7	30 (86)	27 d	Resistant	...	112
Inconel 600	N06600	...	Test tank, simulating action of tank car. Aeration: none. Agitation: by rocking of tank.	73	95-100 (203-212)	111 d	0.003 (0.1)	...	112
Inconel 600	N06600	...	Transfer piping, at pump discharge. Aeration: moderate. Agitation: by 100 gal/min flow from pump	50	60-70 (140-158)	393 d	0.003 (0.1) max	...	112
Inconel 601	N06601	...	...	10	80 (176)	672 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	10	Boiling	168 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	20	80 (176)	672 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	20	Boiling	168 h	0.005 (0.2)	...	64
Inconel 601	N06601	...	...	30	80 (176)	672 h	0.005 (0.2)	...	64
Inconel 601	N06601	...	...	30	Boiling	168 h	0.018 (0.7)	...	64
Inconel 601	N06601	...	...	40	80 (176)	672 h	0.010 (0.4)	...	64
Inconel 601	N06601	...	...	40	Boiling	168 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	50	80 (176)	672 h	0.003 (0.1)	...	64
Inconel 601	N06601	...	...	50	Boiling	168 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	60	80 (176)	672 h	0.008 (0.3)	...	64
Inconel 601	N06601	...	...	60	Boiling	168 h	0.003 (0.1) max	...	64
Inconel 601	N06601	...	...	70	80 (176)	672 h	0.018 (0.7)	...	64

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 601	N06601	...	...	70	Boiling	168 h	0.005 (0.2)	...	64
Inconel 601	N06601	...	...	98	Molten	168 h	0.076 (3.0)	...	64
Monel 400	N04400	...	...	50	40 (100)	162 d	0.003 (0.1) max	...	111
Monel 400	N04400	...	...	50	60 (135)	135 d	0.003 (0.1) max	...	111
Monel 400	N04400	...	...	50	55-75 (130-165)	30 d	0.003 (0.1) max	...	112
Monel 400	N04400	...	...	70-73	110 (230)	126 d	0.003 (0.1)	...	111
Monel 400	N04400	...	...	70-73	90-115 (190-240)	90 d	0.028 (1.1)	...	112
Monel 400	N04400	...	...	70-73	120 (240)	180 d	0.013 (0.5)	...	113
Monel 400	N04400	...	...	70-73	130 (265)	200 d	0.023 (0.9)	...	113
Monel 400	N04400	...	...	5	Room	...	0.003 (0.1) max	...	116
Monel 400	N04400	...	...	15	Room	...	0.003 (0.1) max	...	116
Monel 400	N04400	...	...	25	Room	...	0.003 (0.1) max	...	116
Monel 400	N04400	...	...	35	Room	...	0.003 (0.1) max	...	116
Monel 400	N04400	...	...	45	Room	...	0.003 (0.1) max	...	116
Monel 400	N04400	...	...	5-10	21 (70)	124 d	0.008 (0.3)	...	112
Monel 400	N04400	...	Average of tests run at eight separate labs. Aeration: air agitated. Agitation: air agitated	4	30 (86)	2 d	0.005 (0.2)	...	112
Monel 400	N04400	...	Average of tests run at eight separate labs. Aeration: none. Agitation: none	4	30 (86)	2 d	0.005 (0.2)	...	112
Monel 400	N04400	...	Concentration in caustic evaporator. Concentration: 60 to nearly anhydrous. Aeration: none. Agitation: none	...	150-260 (302-500)	2 d	0.34 (13)	...	112
Monel 400	N04400	...	Coupons in railroad tank car. Aeration: not specified. Agitation: by movement of tank car	74	130 (266)	9 d	0.01 (0.4)	...	112
Monel 400	N04400	...	Diaphragm cell	50	35-90 (95-190)	19 h	0.003 (0.1) max	...	114
Monel 400	N04400	...	Diaphragm cell	73	100-125 (212-260)	...	0.01 (0.4)	...	114
Monel 400	N04400	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl	10	80 (180)	207 d	Resistant	...	111
Monel 400	N04400	...	First effect of a multi-effect evaporator	14	90 (190)	90 d	0.003 (0.1)	...	112
Monel 400	N04400	...	First effect of multiple-effect evaporator. Aeration: none. Agitation: none	14	88 (190)	90 d	0.003 (0.1)	...	112
Monel 400	N04400	...	Lab test	50	150 (300)	...	0.013 (0.5)	...	113
Monel 400	N04400	...	Lab test on tubing; average of four coupons. Aeration: none. Agitation: none	50	150 (302)	...	...	...	112
Monel 400	N04400	...	Lab test. NaOH concentrated to anhydrous	75	480 (900)	...	6.6 (260)	...	114
Monel 400	N04400	...	Lab tests	20	149 (332)	19 d	Resistant	...	112
Monel 400	N04400	...	Lab tests	40	149 (332)	29 d	0.05 (3)	...	112
Monel 400	N04400	...	Lab tests	60	149 (332)	19 d	0.025 (1)	...	112
Monel 400	N04400	...	Mercury cell	50	40-80 (100-180)	...	0.003 (0.1) max	...	114
Monel 400	N04400	...	Mercury cell	73	115 (240)	...	0.013 (0.5)	...	114
Monel 400	N04400	...	Molten	...	400 (750)	...	0.05 (1.8)	...	112
Monel 400	N04400	...	Molten	...	500 (932)	...	0.13 (5)	...	112
Monel 400	N04400	...	Molten	...	580 (1076)	...	0.4 (18)	...	112
Monel 400	N04400	...	Molten	...	680 (1256)	...	...	...	112
Monel 400	N04400	...	NaCl concentration unknown	72	121 (250)	29 d	0.008 (0.3)	...	112
Monel 400	N04400	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.005 (0.2)	...	112
Monel 400	N04400	...	NaCl concentration, 12%	10	88 (190)	29 d	0.003 (0.1) max	...	112
Monel 400	N04400	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	0.03 (1)	...	112
Monel 400	N04400	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.008 (0.3)	...	112

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel 400	N04400	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and NA_2NO_3	73	540 (1000)	2.5 d	9.7 (380)	...	114
Monel 400	N04400	...	Single-effect evaporator. Rates are average of three tests. Aeration: noneAgitation: none	30-50	81 (178)	16 d	0.005 (0.19)	...	112
Monel 400	N04400	...	Storage tank between evaporator and finishing pots. Ammonia soda process. Aeration: not specfied. Agitation: due to filling tank	75	135 (271)	35 d	0.04 (1.7)	...	112
Monel 400	N04400	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	73	104-116 (244-251)	126 d	0.003 (0.1)	...	112
Monel 400	N04400	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	49-51	55-75 (131-167)	30 d	0.003 (0.1) max	...	112
Monel 400	N04400	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	22	50-60 (120-140)	133 h	0.003 (0.1) max	...	112
Monel 400	N04400	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	73	100-120 (212-248)	52 d	0.003 (0.1) max	...	112
Monel 400	N04400	...	Storage tank in which air was bubbled through from bottom. Aeration: extensive. Agitation: mild	34	65 (150)	37 d	Resistant	...	112
Monel 400	N04400	...	Storage tank. Aeration: extensive. Agitation: due to filling the tank	5-10	21-32 (70-90)	124 d	0.008 (0.3)	...	112
Monel 400	N04400	...	Storage tank. Aeration: moderate. Agitation: due to filling tank	72	121 (282)	119 d	0.008 (0.3)	...	112
Monel 400	N04400	...	Storage tank. Aeration: none. Agitation: due to filling tank	50	55-61 (131-142)	135 d	0.003 (0.1) max	...	112
Monel 400	N04400	...	Storage tank. Aeration: none. Agitation: due to filling tank	72-73	116 (273)	183 h	0.02 (0.7)	...	112
Monel 400	N04400	...	Test coupons removed, cleaned and dried each day for 30 d. Aeration: none. Agitation: none	0.7	30 (86)	...	0.003 (0.1) max	...	112
Monel 400	N04400	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.005 (0.2)	...	113
Monel 400	N04400	...	Test tank, simulating action of tank car. Aeration: none. Agitation: by rocking of tank	73	95-100 (203-212)	111 d	0.004 (0.2)	...	112
Monel 400	N04400	...	Transfer piping, at pump discharge. Aeration: moderate. Agitation: by 100 gal/min flow from pump	50	60-70 (140-158)	393 d	0.003 (0.1)	...	112
Nickel	N02200	...	...	35	93 (199)	100 d	.0051 (0.20)	...	221
Nickel	N02200	...	...	50	93 (199)	100 d	.0051 (0.20)	...	221
Nickel	N02200	...	...	73	120 (248)	100 d	.0051 (0.20)	...	221
Nickel	N02200	...	Plus 5% NaCl	45	40 (104)	100 d	.0025 (0.10)	...	221
Nickel	N02200	...	Plus 5% NaCl	45	140 (284)	100 d	.080 (3.2)	...	221
Nickel 200	N02200	...	...	50	40 (100)	162 d	0.003 (0.1) max	...	111
Nickel 200	N02200	...	...	50	60 (135)	135 d	0.003 (0.1) max	...	111
Nickel 200	N02200	...	...	50	55-75 (130-165)	30 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	...	70-73	110 (230)	126 d	0.003 (0.1)	...	111
Nickel 200	N02200	...	...	70-73	90-115 (190-240)	90 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	...	70-73	120 (240)	180 d	0.005 (0.2)	...	113
Nickel 200	N02200	...	...	70-73	130 (265)	200 d	0.025 (1)	...	113
Nickel 200	N02200	...	...	5	Room	2.5 d	0.003 (0.1) max	...	116
Nickel 200	N02200	...	...	15	Room	...	0.003 (0.1) max	...	116
Nickel 200	N02200	...	...	25	Room	...	0.003 (0.1) max	...	116

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	...	35	Room	...	0.003 (0.1) max	...	116
Nickel 200	N02200	...	...	45	Room	...	0.003 (0.1) max	...	116
Nickel 200	N02200	...	...	5-10	21 (70)	124 d	0.005 (0.2)	...	112
Nickel 200	N02200	...	Average of tests run at eight separate labs. Aeration: air agitated. Agitation: air agitated	4	30 (86)	2 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	Average of tests run at eight separate labs. Aeration: none. Agitation: none	4	30 (86)	2 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	Chemically pure	75	...	...	0.015 (0.6)	...	112
Nickel 200	N02200	...	Commercial. Sulfur content at start, calculated as H_2S, 0.009%	50-75	...	...	0.04 (1.7)	...	112
Nickel 200	N02200	...	Concentration in caustic evaporator. Concentration: 60 to nearly anhydrous. Aeration: none. Agitation: none	...	150-260 (302-500)	2 d	0.10 (3.9)	...	112
Nickel 200	N02200	...	Coupons in railroad tank car. Aeration: not specified. Agitation: by movement of tank car. Eleven trips of 7-9 days	74	130 (266)	9 d	0.008 (0.3)	...	112
Nickel 200	N02200	...	Diaphragm cell	50	35-90 (95-190)	...	0.003 (0.1) max	...	114
Nickel 200	N02200	...	Diaphragm cell	73	100-125 (212-260)	...	0.003 (0.2) max	...	114
Nickel 200	N02200	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl	10	80 (180)	207 d	0.003 (0.1) max	...	111
Nickel 200	N02200	...	First effect of a multi-effect evaporator.	14	90 (190)	190 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	First effect of multiple-effect evaporator. Aeration: none. Agitation: none	14	88 (190)	90 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	First effect of multiple-effect evaporator. Aeration: none. Agitation: none	14	88 (190)	90 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	In caustic soda at atmospheric pressure	50	30 (86)	120 h	0.003 (0.1)	...	44
Nickel 200	N02200	...	In caustic soda at atmospheric pressure	50	30 (86)	24 h	0.007 (0.3)	...	44
Nickel 200	N02200	...	In caustic soda at atmospheric pressure	50	130 (266)	720 h	0.027 (1.1)	...	44
Nickel 200	N02200	...	In caustic soda at atmospheric pressure	50	150 (302)	336 h	0.010 (0.4)	...	44
Nickel 200	N02200	...	In caustic soda at atmospheric pressure	50	154 (310)	672 h	0.012 (0.5)	...	44
Nickel 200	N02200	...	In caustic soda at atmospheric pressure; velocity 15 ft/min	50	90 (195)	24 h	0.013 (0.55)	...	44
Nickel 200	N02200	...	In caustic soda. Pressure, 5 psi; velocity, 75 ft/min	50	154 (310)	20 h	0.03 (1.2)	...	44
Nickel 200	N02200	...	In caustic soda. Pressure, 610 mm	50	100 (212)	24 h	0.02 (0.7)	...	44
Nickel 200	N02200	...	In caustic soda. Pressure, 610 mm	50	100 (212)	240 h	0.003 (0.07)	...	44
Nickel 200	N02200	...	In caustic soda. Pressure, 620 mm	50	100 (212)	264 h	0.012 (0.5)	...	44
Nickel 200	N02200	...	Lab spray test in caustic soda	4	Room	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Lab test in castic soda. Continuous alternate immersion	4	Room	...	0.012 (0.5)	...	44
Nickel 200	N02200	...	Lab test in caustic soda	75	121 (250)	...	0.025 (1)	...	44
Nickel 200	N02200	...	Lab test in caustic soda. Air-agitated immersion	4	Room	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Lab test in caustic soda. Intermittent alternate immersion	4	Room	...	0.015 (0.6)	...	44
Nickel 200	N02200	...	Lab test in caustic soda. Quiet immersion	4	Room	...	0.003 (0.1)	...	44

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	Lab test in caustic soda. Vacuum, 640-685 mm mercury	32-52	84-91 (185-196)	...	0.03 (1.3)	...	44
Nickel 200	N02200	...	Lab test on tubing; average of four coupons. Aeration: none. Agitation: none	50	150 (302)	14 d	...	...	112
Nickel 200	N02200	...	Lab test. NaOH concentrated to anhydrous	75	480 (900)	...	1.8 (72) max	...	114
Nickel 200	N02200	...	Lab tests	50	150 (300)	...	0.013 (0.5)	...	113
Nickel 200	N02200	...	Lab tests	20	110 (262)	15 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	20	115 (272)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	40	110 (262)	15 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	40	115 (272)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	60	110 (262)	15 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	60	115 (272)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	80	110 (262)	15 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	80	115 (272)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	20	162 (355)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	40	162 (355)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	60	162 (355)	19 h	Resistant	...	112
Nickel 200	N02200	...	Lab tests	80	162 (355)	19 h	Resistant	...	112
Nickel 200	N02200	...	Mercury cell	50	40-80 (100-180)	...	0.003 (0.1) max	...	114
Nickel 200	N02200	...	Mercury cell	73	115 (240)	...	0.008 (0.3)	...	114
Nickel 200	N02200	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	NaCl concentration, 12%	10	88 (190)	29 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	NaCl concentration, 6-7%	35-40	116 (240)	29 d	0.01 (0.4)	...	112
Nickel 200	N02200	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	NaCl concentration, unknown	72	121 (250)	29 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	Plant test in electrolytic solution of caustic soda in receiving tank	70	90-115 (194-239)	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Plant test in evaporator with caustic soda	50	...	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Plant test in first effect of multiple-effect evaporator with caustic soda	14	88 (190)	...	0.003 (0.1) max	...	44
Nickel 200	N02200	...	Plant test in single-effect evaporator with caustic soda	30-50	81 (179)	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	Plant test in tank receiving liquor from evaporator with caustic soda	23	104 (220)	...	0.005 (0.2)	...	44
Nickel 200	N02200	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and Na_2NO_3	73	540 (1000)	2.5 d	6.6 (260)	...	114
Nickel 200	N02200	...	Plus 0.75% sodium sulfate	75	...	...	0.02 (0.6)	...	112
Nickel 200	N02200	...	Plus 0.75% sodium sulfide	75	...	...	0.58 (23)	...	112
Nickel 200	N02200	...	Plus 0.75% sodium sulfite	75	...	...	0.13 (5)	...	112
Nickel 200	N02200	...	Plus 0.75% sodium thiosulfate	75	...	...	0.20 (8)	...	112
Nickel 200	N02200	...	Single-effect evaporator. Rates are average of three tests. Aeration: none. Agitation: none	30-50	81 (178)	16 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	Storage tank between evaporator and finishing pots. Ammonia soda process. Aeration: not specfied. Agitation: due to filling tank	75	135 (271)	35 d	0.04 (1.6)	...	112
Nickel 200	N02200	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	49-51	55-75 (131-167)	30 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	Storage tank coupons fully immersed. Aeration: none. Agitation: due to filling tank	73	104-116 (244-251)	126 d	0.003 (0.1) max	...	112

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel 200	N02200	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	22	50-60 (120-140)	133 d	Resistant	...	112
Nickel 200	N02200	...	Storage tank coupons immersed 95% of time. Aeration: none. Agitation: due to filling tank	73	100-120 (212-248)	52 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	Storage tank in which air was bubbled through from bottom. Aeration: extensive. Agitation: mild	34	65 (150)	37 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	Storage tank. Aeration: extensive. Agitation: due to filling tank	5-10	21-32 (70-90)	124 d	0.004 (0.15)	...	112
Nickel 200	N02200	...	Storage tank. Aeration: moderate. Agitation: due to filling tank	72	121 (282)	119 d	0.003 (0.1)	...	112
Nickel 200	N02200	...	Storage tank. Aeration: none. Agitation: due to filling tank	50	55-61 (131-142)	135 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	Storage tank. Aeration: none. Agitation: due to filling tank	72-73	116 (273)	183 d	0.008 (0.3)	...	112
Nickel 200	N02200	...	Test coupons removed, cleaned and dried each day for 30d. Aeration: none. Agitation: none	0.7	30 (86)	27 d	0.003 (0.1) max	...	112
Nickel 200	N02200	...	Test in molten, anhydrous NaOH, plus 0.5% NaCl, 0.5% Na_2CO_3, 0.03% Na_2SO_4	...	510 (950)	4 d	0.23 (9)	...	115
Nickel 200	N02200	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.003 (0.1)	...	113
Nickel 200	N02200	...	Test tank, simulating action of tank car. Aeration: none. Agitation: by rocking of tank	73	95-100 (203-212)	111 d	0.003 (0.13)	...	112
Nickel 200	N02200	...	Tests in storage tank with caustic soda	49-51	55-75 (131-167)	...	0.003 (0.1) max	...	44
Nickel 200	N02200	...	Transfer piping, at pump discharge. Aeration: moderate. Agitation: by 100 gal/min flow from pump	50	60-70 (140-158)	393 d	0.003 (0.1)	...	112
Nickel 201	N02201	...	Molten	...	400 (750)	...	0.02 (0.9)	...	112
Nickel 201	N02201	...	Molten	...	500 (932)	...	0.03 (1.3)	...	112
Nickel 201	N02201	...	Molten	...	580 (1076)	...	0.06 (2.5)	...	112
Nickel 201	N02201	...	Molten	...	680 (1256)	...	1.0 (38)	...	112
Nimonic alloy 75	...	...	Molten	...	400 (750)	...	0.03 (1.1)	...	112
Nimonic alloy 75	...	...	Molten	...	500 (932)	...	0.36 (14)	...	112
Nimonic alloy 75	...	...	Molten	...	580 (1076)	...	0.53 (21)	Pitted	112
Nimonic alloy 75	...	...	Molten	...	680 (1256)	...	1.2 (48)	...	112
Sanicro 28	N08028	...	...	28	99 (210)	7 d	.008 (.32)	...	217
Sanicro 28	N08028	...	...	43	135 (275)	7 d	.074 (2.92)	...	217
Sanicro 28	N08028	...	Plus 6.7% NaCl	43	135 (275)	7 d	.045 (1.8)	...	217
Sanicro 28	N08028	...	Plus 8% NaCl	28	99 (210)	7 d	.008 (.32)	...	217
Refractory metals and alloys									
44Co-31Cr-13W	...	As cast	...	50	65 (150)	...	0.01 (0.3)	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled. As cast	...	50	65 (150)	...	0.015 (0.6)	...	53
50Co-20Cr-15W-10Ni	...	...	...	50	65 (150)	...	Resistant	...	53
53Co-30Cr-4.5W	...	As cast	...	50	65 (150)	...	0.007 (0.3)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F). As cast	...	50	65 (150)	...	0.01 (0.4)	...	53
Cobalt	...	...	Static	10	25 (77)	...	0.02 (0.8)	...	54

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hafnium	...	...	...	50	...	2 d	0.39 (15.3)	...	11
Hafnium	...	...	...	50	...	2 d	0.39 (15.3)	...	11
Haynes alloy 6B	...	...	...	50	Boiling	...	2.74 (108)	...	23
Haynes alloy No.188	R30188	...	...	50	Boiling	...	0.43 (17)	...	23
Haynes alloy No.25	R30605	...	...	50	Boiling	...	0.53 (21)	...	23
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	5	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	5	66 (150)	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	5	Boiling	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	25	Room	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	25	66 (150)	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	50	66 (150)	24 h	Resistant	...	68
Haynes alloy No.25	R30605	Solution heat-treated sheet	...	50	Room	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	5	Room	24 d	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	5	66 (150)	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	5	Boiling	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	25	Room	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	25	66 (150)	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	50	Room	24 h	Resistant	...	68
Multimet	R30155	Solution heat-treated sheet	...	50	66 (150)	24 h	Resistant	...	68
Niobium	R04210	...	...	1-40	Room	...	0.13 (5.0)	...	2
Niobium	R04210	...	...	1-10	98 (208)	...	Questionable	Embrittled	2
TaC-4Co-3Ni-1Cr	...	...	...	5	50 (120)	72 h	0.003 (0.1)	...	147
TaC-4Co-3Ni-1Cr	...	...	...	10	50 (120)	72 h	0.003 (0.1)	...	147
Tantalum	R05210	...	...	5	21 (70)	...	Resistant	...	42
Tantalum	R05210	...	...	5	100 (212)	...	0.02 (0.7)	...	42
Tantalum	R05210	...	...	10	100 (212)	...	0.0254 (1)	...	42
Tantalum	R05210	...	...	40	80 (176)	...	Poor	...	42
Ti-3Al-2.5V, grade 9	...	...	...	50	150 (302)	...	0.5 (19.4)	...	91
Titanium	...	...	...	5-10	21 (70)	124 d	0.001 (0.04)	...	112
Titanium	...	...	...	5-10	21 (70)	...	0.001 (0.04)	...	90
Titanium	...	...	...	10	Boiling	...	0.02 (0.8)	...	1
Titanium	...	...	...	10	Boiling	...	0.021 (0.84)	...	90
Titanium	...	...	...	10	Boiling	...	0.02 (0.8)	...	1
Titanium	...	...	...	28	25 (75)	...	0.003 (0.12)	...	1
Titanium	...	...	...	28	Room	...	0.003 (0.1)	...	90
Titanium	...	...	...	40	66 (150)	...	0.04 (1.5)	...	1
Titanium	...	...	...	40	80 (176)	...	0.13 (5)	...	90
Titanium	...	...	...	40	93 (200)	...	0.06 (2.5)	...	1
Titanium	...	...	...	40	121 (250)	...	0.13 (5)	...	1
Titanium	...	...	...	50	57 (135)	...	0.013 (0.5)	...	90
Titanium	...	...	...	50	38 (100)	...	0.023 (0.9)	...	90
Titanium	...	...	...	50	66 (150)	...	0.018 (0.7)	...	1
Titanium	...	...	...	50	150 (302)	...	0.05 (2.2)	...	91
Titanium	...	...	...	50	40 (100)	162 d	0.003 (0.1) max	...	111

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	...	50	60 (135)	135 d	0.013 (0.5)	...	111
Titanium	...	...	...	50	Boiling	...	0.051 (2.04)	...	90
Titanium	...	...	...	50-73	188 (370)	...	1.1 (43.3) min	...	1
Titanium	...	...	...	50-73	188 (370)	...	1.09 (43.6) min	...	90
Titanium	...	...	...	50-73	188 (370)	...	1.1 (43.3) min	...	1
Titanium	...	...	...	73	110 (230)	...	0.05 (2)	...	1
Titanium	...	...	...	73	Boiling	...	0.13 (5)	...	1
Titanium	...	...	...	73	129 (265)	...	0.18 (7)	...	90
Titanium	...	...	...	73	110 (230)	...	0.05 (2)	...	1
Titanium	...	...	...	73	Boiling	...	0.13 (5)	...	1
Titanium	...	...	...	70-73	110 (230)	126 d	0.05 (2)	...	111
Titanium	...	...	...	70-73	130 (265)	200 d	0.18 (7)	...	113
Titanium	...	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl	10	80 (180)	207 d	Resistant	...	111
Titanium, grade 9	...	...	...	50	150 (302)	...	0.49 (19)	...	33
Zirconium	R60701	...	...	50	40 (100)	162 d	0.003 (0.1)	...	111
Zirconium	R60701	...	...	50	60 (135)	135 d	0.003 (0.1)	...	111
Zirconium	R60701	...	...	70-73	110 (230)	126 d	0.02 (0.8)	...	111
Zirconium	R60701	...	...	70-73	130 (265)	200 d	0.05 (2)	...	113
Zirconium	R60701	...	...	5-10	21 (70)	124 d	0.005 (0.2)	Slight pitting	112
Zirconium	R60701	...	Exposure to effluent from an electrolytic chlorine cell containing 15% NaCl	10	80 (180)	207 d	0.003 (0.1)	...	111
Zirconium	R60701	...	Plant test. NaOH concentrated to anhydrous. Batch shaded with sulfur and Na_2NO_3	73	540 (1000)	2.5 d	2.8 (110)	...	114
Zr702	R60702	...	...	5-10	21 (70)	...	0.03 (1) max	...	15
Zr702	R60702	...	...	28	Room	...	0.03 (1) max	...	15
Zr702	R60702	...	...	10-25	Boiling	...	0.03 (1) max	...	15
Zr702	R60702	...	...	40	100 (212)	...	0.03 (1) max	...	15
Zr702	R60702	...	...	50	38-57 (100-135)	...	0.03 (1) max	...	15
Zr702	R60702	...	...	50-73	188 (370)	...	1.3 (50) max	...	15
Zr702	R60702	...	...	73	110-129 (230-265)	...	0.05 (2) max	...	15
Zr702	R60702	...	Concentrated to anhydrous	73	212-538 (415-1000)	...	1.3 (50) max	...	15
Zr702	R60702	...	Plus 10% NaCl, wet $CaCl_2$	10	10-32 (50-90)	...	0.03 (1) max	...	15
Zr702	R60702	...	Plus 15% NaCl	9-11	82 (180)	...	0.03 (1) max	...	15
Zr702	R60702	...	Plus 16% NH_3	52	138 (280)	...	0.13 (5) max	...	15
Zr702	R60702	...	Plus 2% $NaClO_3$, and a trace of NH_3.	0.6%	129 (265)	...	0.03 (1) max	...	15
Zr702	R60702	...	Plus 53% NaCl, 7% $NaClO_3$, 80-100 ppm NH_3	7	191 (375)	...	0.03 (1) max	...	15
Zr702	R60702	...	Plus 750 ppm free Cl_2	50	38 (100)	...	0.025 (1) max	...	15
Zr702	R60702	...	Plus 750 ppm free Cl_2	50	38-57 (100-135)	...	0.025 (1) max	...	15
Zr702	R60702	...	Suspended salt, violent boiling	20	60 (140)	...	015.5 (20) max	...	15
Stainless steels									
14Cr	S40500	...	Test in single-effect evaporator	30-50	80 (180)	16 d	0.84 (33)	...	113
18.5%Cr	S44200	...	Lab test. NaOH conentrated to anhydrous	75	480 (900)	...	70 (2700)	...	114
20, cast alloys only	J95150	...	Diaphragm cell	50	35-90 (95-190)	...	0.0025 (0.1) max	...	114
20, cast alloys only	J95150	...	Diaphragm cell	73	100-125 (212-260)	...	0.09 (3.5)	...	114
20, cast alloys only	J95150	...	Mercury cell	50	40-80 (100-180)	...	0.0025 (0.1) max	...	114
20, cast alloys only	J95150	...	Mercury cell	73	115 (240)	...	0.01 (0.4)	...	114
20Cb-3	N08020	...	Diaphragm cell	50	35-90 (95-190)	...	0.0025 (0.1) max	...	114
20Cb-3	N08020	...	Diaphragm cell	73	100-125 (212-260)	...	0.02 (0.8)	...	114
20Cb-3	N08020	...	Mercury cell	50	40-80 (100-180)	...	0.0025 (0.1) max	...	114

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
20Cb-3	N08020	...	Mercury cell	73	115 (240)	...	0.01 (0.4)	...	114
21Cr-4Ni-0.5Cu	...	...	Solution moderately agitated	72	120-125 (245-255)	119 d	0.15 (6)	...	115
301	S30100	...	...	25	20 (68)	...	Resistant	...	253
301	S30100	...	...	25	Boiling	...	Good	...	253
301	S30100	...	Fused	50	Boiling	...	Questionable	...	253
301	S30100	...	Fused	50	320 (608)	...	Poor	...	253
302	S30200	...	...	20	50-60 (120-140)	134 d	0.0025 (0.1) max	...	115
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Good	...	253
302	S30200	...	Fused	50	Boiling	...	Questionable	...	253
302	S30200	...	Fused	50	320 (608)	...	Poor	...	253
302	S30200	...	Lab test. NaOH conentrated to anhydrous	75	480 (900)	...	45.7 (1800)	...	114
302	S30200	...	No aeration	73	100-120 (210-245)	88 d	0.97 (38)	...	115
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Questionable	...	253
303	S30300	...	...	25	Boiling	...	Good	...	253
303	S30300	...	Fused	50	Boiling	...	Questionable	...	253
303	S30300	...	Fused	50	Boiling	...	Questionable	...	253
303	S30300	...	Fused	50	320 (608)	...	Poor	...	253
303	S30300	...	Fused	50	320 (608)	...	Poor	...	253
304	S30400	...	...	5	Room	...	0.0025 (0.1)	...	116
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	15	Room	...	0.0025 (0.1) max	...	116
304	S30400	...	...	22	50-60 (120-140)	133 d	0.0025 (0.1) max	...	115
304	S30400	...	...	25	Room	...	0.0025 (0.1) max	...	116
304	S30400	...	...	30	20 (68)	30 d	0.003 (0.1) max	...	89
304	S30400	Sensitized (650°C for 10 h, air cooled)	...	30	100 (212)	72 h	...	Intergranular	148
304	S30400	...	...	35	Room	...	0.003 (0.1) max	...	116
304	S30400	...	...	45	Room	...	0.0025 (0.1) max	...	116
304	S30400	...	...	50	55-75 (130-165)	30 d	0.003 (0.1)	...	112
304	S30400	...	...	70-73	90-115 (190-240)	90 d	0.69 (27)	...	112
304	S30400	...	...	70-73	120 (240)	180 d	0.26 (10.2)	...	113
304	S30400	...	...	50	143 (290)	...	4.6 (183)	...	223
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Good	...	253
304	S30400	...	Chemical processing; field or plant test; slight to moderate aeration; slight to moderate agitation	72	121 (250)	119 d	0.09 (3.7)	...	89
304	S30400	...	Chemical processing; field or plant test; slight to moderated aeration; slight to moderate agitation. Caustic cell liquor, plus 12% salt	10	87 (190)	279 d	0.005 (0.2)	...	89
304	S30400	...	Diaphragm cell	50	35-90 (95-190)	...	0.005 (0.2)	...	114
304	S30400	...	Diaphragm cell	73	100-125 (212-260)	...	0.4 (15.8)	...	114
304	S30400	...	Fused	50	Boiling	...	Questionable	...	253
304	S30400	...	Fused	50	320 (608)	...	Poor	...	253
304	S30400	...	Lab test	50	150 (300)	...	1.2 (47)	...	113
304	S30400	...	Lab test; rapid agitation. Plus occasionally some sulfuric acid	3-10	87 (190)	300 d	0.75 (30)	Slight pitting	89
304	S30400	...	Mercury cell	50	40-80 (100-180)	...	0.019 (0.75)	...	114
304	S30400	...	Mercury cell	73	115 (240)	...	0.38 (15)	...	114

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	NaCl concentration unknown	72	121 (250)	29 d	0.10 (4)	...	112
304	S30400	...	NaCl concentration unknown	72	121 (250)	29 d	0.008 (0.3)	...	112
304	S30400	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.01 (0.2)	...	112
304	S30400	...	NaCl concentration, 10-15%	50	93 (200)	29 d	0.102 (0.4)	...	112
304	S30400	...	NaCl concentration, 12%	10	88 (190)	29 d	0.005 (0.2)	...	112
304	S30400	...	NaCl concentration, 12%	10	88 (190)	29 d	0.0025 (0.1) max	...	112
304	S30400	...	NaCl concentration, 6-7%	35-40	115 (240)	29 d	0.025 (1)	...	112
304	S30400	...	NaCl concentration, 6-7%	35-40	115 (240)	29 d	0.051 (2)	...	112
304	S30400	...	NaCl concentration, 6-7%	35-40	115 (240)	29 d	0.0229 (0.9)	...	112
304	S30400	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.01 (0.4)	...	112
304	S30400	...	NaCl concentration, 7-8%	23	93 (200)	29 d	0.051 (2)	...	112
304	S30400	...	No activation	25	100 (212)	24 h	0.0275 (1.1)	...	52
304	S30400	...	No activation	35	100 (212)	24 h	0.044 (2.2)	...	52
304	S30400	...	No activation	60	100 (212)	24 h	0.06 (3.0)	...	52
304	S30400	...	No aeration	73	100-120 (210-245)	88 d	1.1 (45)	...	115
304	S30400	...	No aeration; no agitation	49-51	65 (150)	30 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; no agitation	70	90-143 (194-239)	90 d	0.68 (27)	...	89
304	S30400	...	No aeration; no agitation	73	120-160 (248-320)	34 d	2.8 (113)	...	89
304	S30400	...	No aeration; no agitation	75	135 (275)	35 d	0.1 (5)	Slight pitting	89
304	S30400	...	No aeration; no agitation. Multiple effect evaporator	14	87 (190)	90 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; no agitation; with carbon over the standard maximum	75	135 (275)	35 d	0.2 (7)	Slight pitting	89
304	S30400	...	No aeration; rapid agitation. Approx. 20% suspended crystalline salt, evaporator	20	60 (140)	196 d	.08 (1.4)	...	89
304	S30400	...	No aeration; rapid agitation. Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; rapid agitation; sensitized. Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; slight to moderate agitation	22	55 (131)	133 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; slight to moderate agitation	73	110 (230)	88 d	1.1 (45)	...	89
304	S30400	...	No aeration; slight to moderate agitation	73	110 (230)	52 d	0.2 (9)	...	89
304	S30400	...	No aeration; slight to moderate agitation. Plus naphthenic acid, cresols, phenols, 0.04% mercaptan, sulfur, tower	18	107 (225)	660 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; slight to moderate agitation. Plus naphthenic acid, cresols, phenols, 0.04% mercaptan, sulfur, tower	18	107 (225)	564 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; slight to moderate agitation; Plus 10% sulfuric acid, 0.1% sulfur dioxide, pH 4.3	2	52 (125)	104 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; slight to moderate agitation; with carbon over the standard maximum	22	55 (131)	133 d	0.003 (0.1) max	...	89
304	S30400	...	No aeration; slight to moderate agitation; with carbon over the standard maximum	73	110 (230)	88 d	1.0 (38)	...	89
304	S30400	...	No aeration; slight to moderate agitation; with carbon over the standard maximum	73	110 (230)	52 d	0.2 (9)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	No aeration; with carbon over the standard maximum. Plus % sodium hypochlorite, gas scrubber. Concentration-cell corrosion	6	27-32 (80-90)	138 d	0.6 (24)	Severe pitting; crevice attack	89
304	S30400	...	No agitation. Plus 3 ppm chloride ion, vapors	35	260 (500)	21 d	...	Stress-corrosion cracking	89
304	S30400	...	Plastic distillation; no aeration; rapid agitation. Plus 2-7% potassium hydroxide, still pot in cracking column	20	152 (305)	60 d	0.003 (0.1) max	...	89
304	S30400	...	Selective dissolution. General corrosion	40	90 (194)	72 h	...	...	148
304	S30400	...	Slight to moderate aeration; rapid agitation. Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.01 (0.3)	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus 12% amine salt, 8% methanol, 7% sodium chloride	1.5-15	28 (85)	20 d	0.003 (0.1)	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus mercaptans, cresolates	18-22	37-104 (100-220)	30 d	0.003 (0.1)	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus sodium hydrosulfide, sodium sulfide, intermittent exposure to air, steam, and hydrogen sulfide	...	75 (167)	15 d	0.01 (0.2)	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus sulfur dioxide, normally acid solution	...	54-60 (130-140)	99 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus sulfur dioxide, normally alkaline solution	...	54-60 (130-140)	99 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation; sensitized. Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1)	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation; with carbon over the standard maximum. Plus mercaptans cresolates	18-22	37-104 (100-220)	30 d	0.003 (0.1)	...	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation	50	58 (136)	167 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Approx. 23%, plus 7-8% salt	23	93 (200)	48 d	0.01 (0.4)	...	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Approx. 35-40%, plus 6-7% salt, salt settler	35-40	115 (240)	24 d	0.03 (1)	...	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Plus 10-15% sodium chloride	50	93 (200)	119 d	0.01 (0.2)	...	89
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Plus 99.5% water, traces of butane and kerosene	0.5	160 (320)	275 d	Resistant	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Slight to moderate aeration; slight to moderate agitation. Plus organic material, sulfuric acid, arsenious acid (in resin of ion exchanger)	...	76 (167)	30 d	0.003 (0.1)	...	89
304	S30400	...	Soap processing; rapid agitation. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.003 (0.1) max	Severe pitting; crevice attack	89
304	S30400	...	Soap processing; rapid agitation. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.003 (0.1)	Moderate pitting	89
304	S30400	...	Soap processing; rapid agitation; with carbon over the standard maximum. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.003 (0.1)	Slight pitting	89
304	S30400	...	Soap processing; rapid agitation; with carbon over the standard maximum. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.003 (0.1) max	Severe pitting; crevice attack	89
304	S30400	...	Solution moderately agitated	72	120-125 (245-255)	119 d	0.09 (3.7)	...	115
304	S30400	...	Uniform corrosion	40	110 (230)	72 h	...	...	148
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Good	...	253
304L	S30403	...	Fused	50	Boiling	...	Questionable	...	253
304L	S30403	...	Fused	50	320 (608)	...	Poor	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Good	...	253
304LN	S30453	...	Fused	50	Boiling	...	Questionable	...	253
304LN	S30453	...	Fused	50	320 (608)	...	Poor	...	253
309	S30900	...	...	20	50-60 (120-140)	134 d	0.0025 (0.1) max	...	115
310	S31000	...	...	20	50-60 (120-140)	134 d	0.0025 (0.1) max	...	115
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	25	95 (203)	72 h	...	...	148
316	S31600	...	...	50	Boiling	...	3.12 (123)	...	120
316	S31600	...	...	50	Boiling	...	2.5 (100) min	...	120
316	S31600	Welded	...	50	Boiling	...	3.45 (136)	...	120
316	S31600	...	...	50	130 (266)	72 h	...	Intergranular corrosion	148
316	S31600	...	...	...	...	100 d	.064 (2.5)	...	221
316	S31600	...	...	...	...	100 d	.028 (1.1)	...	221
316	S31600	...	...	...	...	100 d	.052 (2.0)	...	221
316	S31600	...	...	...	...	100 d	.332 (13.1)	...	221
316	S31600	...	...	50	143 (290)	...	3.1 (123)	...	223
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Chemical distillation; no aeration; slight to moderate agitation. Plus 2% chlorine-saturated monochlorotoluene, and approx. 2% hydrochloric acid, batch still	15	100 (212)	33 d	0.21 (23)	Severe pitting; crevice attack	89
316	S31600	...	Diaphragm	50	35-90 (95-190)	...	0.017 (0.65)	...	114
316	S31600	...	Diaphragm cell	73	100-125 (212-260)	...	0.24 (9.3)	...	114
316	S31600	...	Fused	50	Boiling	...	Questionable	...	253
316	S31600	...	Fused	50	320 (608)	...	Poor	...	253
316	S31600	...	Lab test; rapid agitation. Plus occasionally some sulfuric acid	3-10	87 (190)	300 d	0.0083 (8.3)	...	89
316	S31600	...	Mercury cell	50	40-80 (100-180)	...	0.0025 (0.1)	...	114
316	S31600	...	Mercury cell	73	115 (240)	...	0.25 (10)	...	114
316	S31600	...	No activation	25	100 (212)	24 h	0.0475 (1.9)	...	52
316	S31600	...	No activation	35	100 (212)	24 h	0.04 (1.6)	...	52
316	S31600	...	No activation	60	100 (212)	24 h	0.0675 (2.7)	...	52
316	S31600	...	No aeration; no agitation	73	120-160 (248-320)	34 d	2.5 (100)	...	89
316	S31600	...	No aeration; no agitation	75	135 (275)	35 d	0.2 (7)	Slight pitting	89
316	S31600	...	No aeration; rapid agitation. Approx. 20% suspended crystalline salt, evaporator	20	60 (140)	196 d	0.09 (3.6)	...	89
316	S31600	...	No aeration; rapid agitation. Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
316	S31600	...	No aeration; rapid agitation; sensitized. Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1)	...	89
316	S31600	...	No aeration; slight to moderate agitation. Plus naphthenic acid, cresols, phenols, 0.04% mercaptan sulfur, tower	18	107 (225)	660 d	0.01 (0.2)	...	89
316	S31600	...	No aeration; slight to moderate agitation. Plus naphthenic acid, cresols, phenols, 0.04% mercaptan, sulfur, tower	18	107 (225)	660 d	0.003 (0.1)	...	89
316	S31600	...	No aeration; slight to moderate agitation; Plus 10% sulfuric acid, 0.1% sulfur dioxide, pH 4.3	2	52 (125)	104 d	0.003 (0.1) max	...	89
316	S31600	...	Petrochemical processing; no aeration; with carbon over the standard maximum. Plus % sodium hypochlorite, gas scrubber. Concentration-cell corrosion	6	27-32 (80-90)	138 d	0.022 (22)	Severe pitting; crevice attack	89
316	S31600	...	Plastic distillation; no aeration; rapid agitation. Plus 2-7% potassium hydroxide, still pot in cracking column	20	152 (305)	60 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.01 (0.3)	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus mercaptans, cresolates	18-22	37-104 (100-220)	30 d	0.01 (0.4)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus sodium hydrosulfide, sodium sulfide, intermittent exposure to air, steam, and hydrogen sulfide (as absorption column)	...	75 (167)	15 d	0.01 (0.4)	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus sulfur dioxide, normally acid solution	...	54-60 (130-140)	99 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus sulfur dioxide, normally alkaline solution	...	54-60 (130-140)	99 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation; low-carbon grade (0.03% carbon maximum). Plus 12% amine salt, 8% methanol, 7% sodium chloride	1.5-15	28 (85)	20 d	0.01 (0.2)	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation; sensitized. Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1)	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation	72	121 (250)	119 d	0.08 (3.1)	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Approx. 23%, plus 7-8% salt	23	93 (200)	48 d	.06 (2.3)	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Approx. 35-40%, plus 6-7% salt, salt settler	35-40	115 (240)	24 d	0.04 (1.5)	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Caustic cell liquor, plus 12% salt	10	87 (190)	279 d	0.0001 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Plus 10-15% sodium chloride	50	93 (200)	119 d	0.01 (0.2)	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Plus 99.5% water, traces of butane and kerosene	0.5	160 (320)	275 d	Resistant	...	89
316	S31600	...	Slight to moderate aeration; slight to moderate agitation. Plus organic material, sulfuric acid, arsenious acid (in resin of ion exchanger)	...	76 (167)	30 d	0.003 (0.1)	...	89
316	S31600	...	Soap processing; rapid agitation. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.003 (0.1) max	Slight pitting	89
316	S31600	...	Soap processing; rapid agitation. Caustic soda lye, plus 10-15% sodium chloride, tallow, coconut oil, glycerine removed with sodium chloride, 0.05-0.15% sodium hydrosulfite added in alkaline solution	23	87 (190)	64 d	0.01 (0.3)	...	89
316	S31600	...	Solution moderately agitated	72	120-125 (245-255)	119 d	0.08 (3.1)	...	115
316	S31600	...	Test; rapid agitation. Tank car	74	129 (265)	88 d	0.21 (8.4)	...	89
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Good	...	253
316F	S31620	...	Fused	50	Boiling	...	Questionable	...	253
316F	S31620	...	Fused	50	320 (608)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Good	...	253
316L	S31603	...	Fused	50	Boiling	...	Questionable	...	253
316L	S31603	...	Fused	50	320 (608)	...	Poor	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Good	...	253
316LN	S31653	...	Fused	50	Boiling	...	Questionable	...	253
316LN	S31653	...	Fused	50	320 (608)	...	Poor	...	253
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Good	...	253
316Ti	S31635	...	Fused	50	Boiling	...	Questionable	...	253
316Ti	S31635	...	Fused	50	320 (608)	...	Poor	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Good	...	253
317L	S31703	...	Fused	50	Boiling	...	Questionable	...	253
317L	S31703	...	Fused	50	320 (608)	...	Poor	...	253
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Good	...	253
317LN	S31725	...	Fused	50	Boiling	...	Questionable	...	253
317LN	S31725	...	Fused	50	320 (608)	...	Poor	...	253
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Good	...	253
321	S32100	...	Fused	50	Boiling	...	Questionable	...	253
321	S32100	...	Fused	50	320 (608)	...	Poor	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Good	...	253
329	S32900	...	Fused	50	Boiling	...	Questionable	...	253
329	S32900	...	Fused	50	320 (608)	...	Poor	...	253
329	S32900	...	Solution moderately agitated	72	120-125 (245-255)	119 d	0.0025 (0.1)	...	115
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Good	...	253
347	S34700	...	Fused	50	Boiling	...	Questionable	...	253
347	S34700	...	Fused	50	320 (608)	...	Poor	...	253
403	S40300	...	...	25	20 (68)	...	Resistant	...	253
403	S40300	...	...	25	Boiling	...	Questionable	...	253
403	S40300	...	Fused	50	Boiling	...	Poor	...	253
403	S40300	...	Fused	50	320 (608)	...	Poor	...	253
405	S40500	...	...	25	20 (68)	...	Resistant	...	253
405	S40500	...	...	25	Boiling	...	Questionable	...	253
405	S40500	...	Fused	50	Boiling	...	Poor	...	253
405	S40500	...	Fused	50	320 (608)	...	Poor	...	253
409	S40900	...	...	25	20 (68)	...	Resistant	...	253
409	S40900	...	...	25	Boiling	...	Questionable	...	253
409	S40900	...	Fused	50	Boiling	...	Poor	...	253
409	S40900	...	Fused	50	320 (608)	...	Poor	...	253
410	S41000	...	...	20	50-60 (120-140)	134 d	0.0025 (0.1)	...	115
410	S41000	...	...	10	21 (70)	...	Resistant	...	121
410	S41000	...	...	25	20 (68)	...	Resistant	...	253
410	S41000	...	...	25	Boiling	...	Questionable	...	253
410	S41000	...	Fused	50	Boiling	...	Poor	...	253
410	S41000	...	Fused	50	320 (608)	...	Poor	...	253
410	S41000	...	Solution moderately agitated	72	120-125 (245-255)	119 d	0.8 (32)	...	115
416	S41600	...	...	25	20 (68)	...	Resistant	...	253
416	S41600	...	...	25	Boiling	...	Questionable	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	Fused	50	Boiling	...	Poor	...	253
416	S41600	...	Fused	50	320 (608)	...	Poor	...	253
420	S42000	...	...	25	20 (68)	...	Resistant	...	253
420	S42000	...	...	25	Boiling	...	Questionable	...	253
420	S42000	...	Fused	50	Boiling	...	Poor	...	253
420	S42000	...	Fused	50	320 (608)	...	Poor	...	253
430	S43000	...	...	10	21 (70)	...	Resistant	...	121
430	S43000	...	...	20	50-60 (120-140)	134 d	0.0025 (0.1)	...	115
430	S43000	...	...	25	20 (68)	...	Resistant	...	253
430	S43000	...	...	25	Boiling	...	Questionable	...	253
430	S43000	...	Diaphragm cell	50	35-90 (95-190)	...	0.01 (0.4)	...	114
430	S43000	...	Diaphragm cell	73	100-125 (212-260)	...	0.97 (38) min	...	114
430	S43000	...	Fused	50	Boiling	...	Questionable	...	253
430	S43000	...	Fused	50	320 (608)	...	Poor	...	253
430	S43000	...	Mercury cell	50	40-80 (100-180)	...	0.14 (5.4) min	...	114
430	S43000	...	Mercury cell	73	115 (240)	...	1.5 (60)	...	114
434	S43400	...	...	25	20 (68)	...	Resistant	...	253
434	S43400	...	...	25	Boiling	...	Questionable	...	253
434	S43400	...	Fused	50	Boiling	...	Questionable	...	253
434	S43400	...	Fused	50	320 (608)	...	Poor	...	253
439	S43035	...	...	50	143 (290)	...	7.8 (306)	...	223
444	S44400	...	...	50	143 (290)	...	7.4 (293)	...	223
444	S44400	...	No activation	25	100 (212)	24 h	0.2 (7.6)	...	52
444	S44400	...	No activation	35	100 (212)	24 h	0.5 (20)	...	52
444	S44400	...	No activation	60	100 (212)	24 h	0.6 (24)	...	52
AL 29-4-2	S44800	...	...	50	Boiling	5 d	0.00 (0.1)	Plain and welded U-bent samples showed no stress-corrosion cracking	81
AL 29-4-2	S44800	...	...	60	Boiling	4 d	0.02 (0.8)	...	81
AL 29-4-2	S44800	...	...	70	Boiling	4 d	0.10 (3.8)	...	81
AL 29-4-2	S44800	...	...	50	143 (290)	...	.002 (0.1)	...	223
AL 29-4-2	S44800	...	Plus 14% NaCl	16	Boiling	4 d	0.00 (0.0)	...	81
AL 29-4-2	S44800	...	Plus 23% NaCl. 0.1% Na_2CO_3, 0.15% $NaClO_3$, 0.01% Na_2SO_4	45	177 (350)	4 d	0.14 (5.6)	...	81
AL 29-4-2	S44800	...	Plus 5% NaCl	45	177 (350)	4 d	0.19 (7.4)	...	81
AL 29-4-2	S44800	...	Plus 5% NaCl	45	149 (300)	4 d	0.04 (1.5)	...	81
AL 29-4-2	S44800	...	Plus 5% NaCl	45	Boiling	4 d	0.00 (0.0)	...	81
AL 29-4-2	S44800	...	Plus 9% NaCl	26	Boiling	4 d	0.00 (0.0)	...	81
AL 29-4C	S44735	...	...	20	121 (250)	...	0.015 (0.6)	...	80
AL 29-4C	S44735	...	...	40	121 (250)	...	0.002 (0.1)	...	80
AL 29-4C	S44735	...	...	60	121 (250)	...	0.007 (0.3)	...	80
AL 29-4C	S44735	...	...	60	157 (315)	...	0.04 (1.6)	...	80
AL 29-4C	S44735	...	...	70	121 (250)	...	0.005 (0.2)	...	80
AL 29-4C	S44735	...	...	70	177 (350)	...	0.048 (1.9)	...	80
AL 29-4C	S44735	...	...	50	143 (290)	...	0.01 (0.4)	...	223
AL 904L	N08904	...	...	50	Boiling	...	0.24 (9.6)	...	120
AL 904L	N08904	...	...	...	...	7 d	.013 (.51)	...	217
AL-6XN	N08367	Welded	...	50	Boiling	...	0.44 (17)	...	120
Alloy 904L	N08904	...	...	...	...	7 d	.301 (11.9)	...	217
Alloy 904L	N08904	...	Plus 6.7% NaCl	...	...	7 d	.349 (13.8)	...	217
Alloy 904L	N08904	...	Plus 8% NaCl	...	...	7 d	.018 (.71)	...	217
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
AM-363	S36300	...	...	50	Room	...	Resistant	...	120

(Continued)

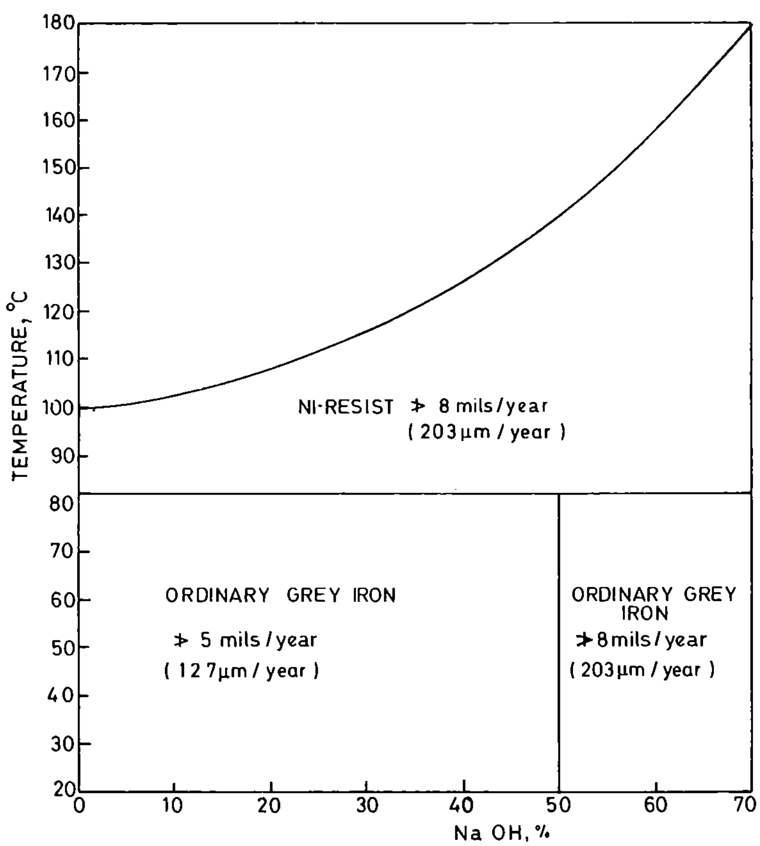
Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	Chemical distillation; no aeration; slight to moderate agitation. Plus 2% chlorine-saturated monochlorotoluene, and approx. 2% hydrochloric acid, batch still	15	100 (212)	33 d	0.6 (22)	Severe pitting; crevice attack	89
Carpenter 20	...	...	Lab test; rapid agitation; cast. Plus occasionally some sulfuric acid	3-10	87 (190)	300 d	0.02 (0.6)	...	89
Carpenter 20	...	...	No aeration; Rapid agitation Plus 12% organic salt, 8% methanol, 7% sodium chloride	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Rapid agitation Tank car	74	129 (265)	88 d	0.02 (0.9)	...	89
Carpenter 20	...	...	Slight to moderate aeration; Rapid agitation Dilute caustic soda, plus sodium formate, methanol, nitrogen compounds	...	30-120 (86-248)	75 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Slight to moderate aeration; Rapid agitation Plus 12% organic salt, 8% methanol, 7% sodium chloride, liquid line	2-17	29 (85)	37 d	0.003 (0.1) max	...	89
CN-7M	J95150	Cast	...	20	150 (334)	18 h	0.3 (10)	...	112
CN-7M	J95150	Cast	...	20	183 (394)	15 h	Resistant	...	112
CN-7M	J95150	Cast	...	40	150 (334)	18 h	0.025 (1)	...	112
CN-7M	J95150	Cast	...	60	152 (336)	19 h	0.3 (12)	...	112
CN-7M	J95150	Cast	...	60	183 (394)	15 h	3.8 (151)	...	112
CN-7M	J95150	Cast	...	80	183 (394)	15 h	0.051 (2)	...	112
E-Brite	S44627	...	...	7.5	102 (215)	5 d	0.000 (0.01)	...	80
E-Brite	S44627	...	...	15	104 (220)	5 d	0.001 (0.04)	...	80
E-Brite	S44627	...	...	25	110 (230)	7 d	0.000 (0.01)	...	80
E-Brite	S44627	...	...	30	116 (240)	5 d	0.001 (0.05)	...	80
E-Brite	S44627	...	...	50	143 (290)	...	0.003 (0.1)	...	80
E-Brite	S44627	...	...	50	143 (290)	5 d	0.003 (0.11)	...	80
E-Brite	S44627	...	...	60	157 (315)	4 d	0.084 (3.3)	...	80
E-Brite	S44627	...	...	70	177 (350)	4 d	0.381 (15) max	...	80
E-Brite	S44627	...	...	50	143 (290)	...	0.002 (0.1)	...	223
E-Brite	S44627	...	Plus 10% NaCl	20	104 (220)	...	0.015 (0.6)	...	80
E-Brite	S44627	...	Plus 5% NaCl	45	143 (290)	...	0.041 (1.6)	...	80
E-Brite	S44627	...	Plus 5% NaCl	50	152 (305)	...	0.076 (3.0)	...	80
E-Brite	S44627	...	Plus 5% NaCl and 0.1% $NaClO_3$	50	152 (305)	...	0.069 (2.7)	...	80
E-Brite	S44627	...	Plus 5% NaCl and 0.2% $NaClO_3$	50	152 (305)	...	0.028 (1.1)	...	80
E-Brite	S44627	...	Plus 5% NaCl and 0.4% $NaClO_3$	50	152 (305)	...	0.028 (1.1)	...	80
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253
F51	S31803	...	...	25	Boiling	...	Good	...	253
F51	S31803	...	Fused	50	Boiling	...	Questionable	...	253
F51	S31803	...	Fused	50	320 (608)	...	Poor	...	253
Ferralium 255	S32550	...	Saturated with NaCl	70	177 (350)	...	...	No stress-corrosion cracking	60
Ferralium alloy 255	S32550	...	Saturated with NaCl	50	143 (290)	...	...	No stress-corrosion cracking	60
Worthite	J95150	Solution quenched	Lab tests	20	132 (270)	19 h	0.1 (4)	...	112
Worthite	J95150	Solution quenched	Lab tests	20	156 (345)	20 h	0.4 (14)	...	112
Worthite	J95150	Solution quenched	Lab tests	20	171 (340)	19 h	0.6 (25)	...	112
Worthite	J95150	Solution quenched	Lab tests	20	171 (340)	19 h	1.8 (69)	...	112
Worthite	J95150	Solution quenched	Lab tests	40	132 (270)	19 h	0.2 (9)	...	112

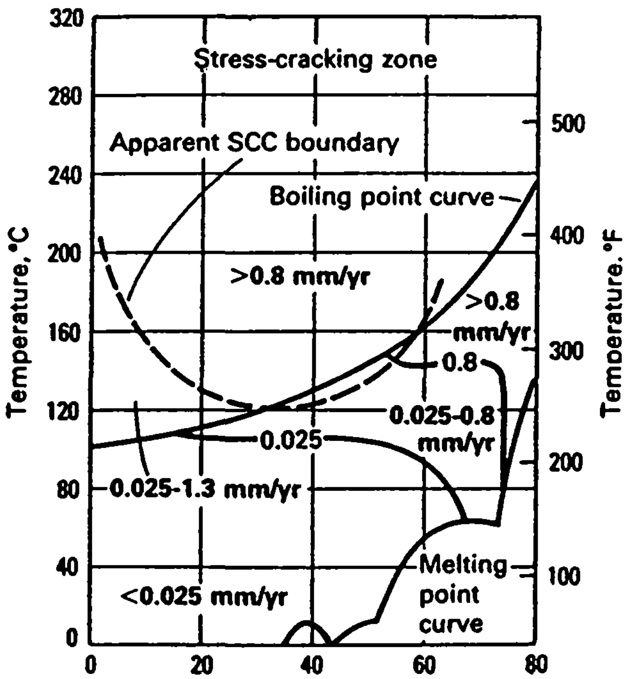
(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hydroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Worthite	J95150	Solution quenched	Lab tests	40	156 (345)	20 h	0.4 (17)	...	112
Worthite	J95150	Solution quenched	Lab tests	40	171 (340)	19 h	0.9 (36)	...	112
Worthite	J95150	Solution quenched	Lab tests	40	171 (340)	19 h	0.7 (28)	...	112
Worthite	J95150	Solution quenched	Lab tests	60	132 (270)	19 h	0.03 (1)	...	112
Worthite	J95150	Solution quenched	Lab tests	60	156 (345)	20 h	0.8 (33)	...	112
Worthite	J95150	Solution quenched	Lab tests	60	171 (340)	19 h	0.05 (2)	...	112
Worthite	J95150	Solution quenched	Lab tests	60	171 (340)	19 h	1.0 (38)	...	112
Worthite	J95150	Solution quenched	Lab tests	80	132 (270)	19 h	Resistant	...	112
Worthite	J95150	Solution quenched	Lab tests	80	171 (340)	19 h	Resistant	...	112
Worthite	J95150	Solution quenched	Lab tests	80	156 (345)	20 h	0.025 (1)	...	112



Cast irons. Corrosion rates of cast irons in sodium hydroxide. Source: H.T. Angus, *Cast Iron: Physical and Engineering Properties*, 2nd ed., Butterworths, London, 1976, 314.



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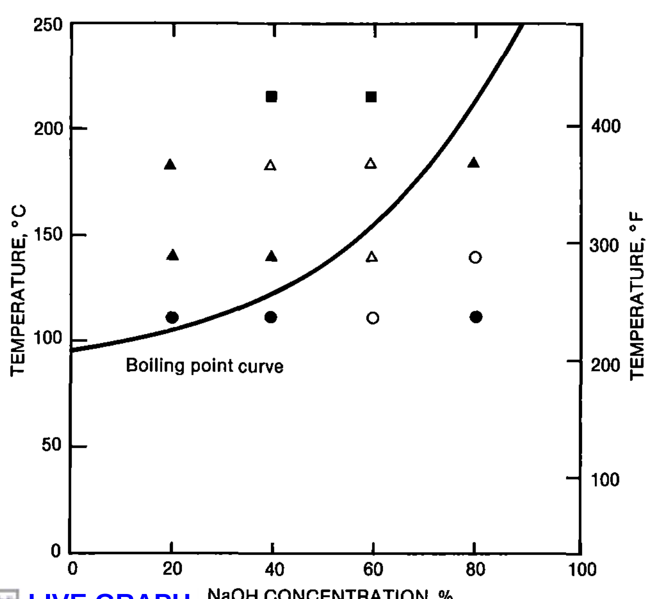
Stainless steel. Isocorrosion diagram for type 304 or 316 stainless steels in sodium hydroxide. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH 1987, 1178.



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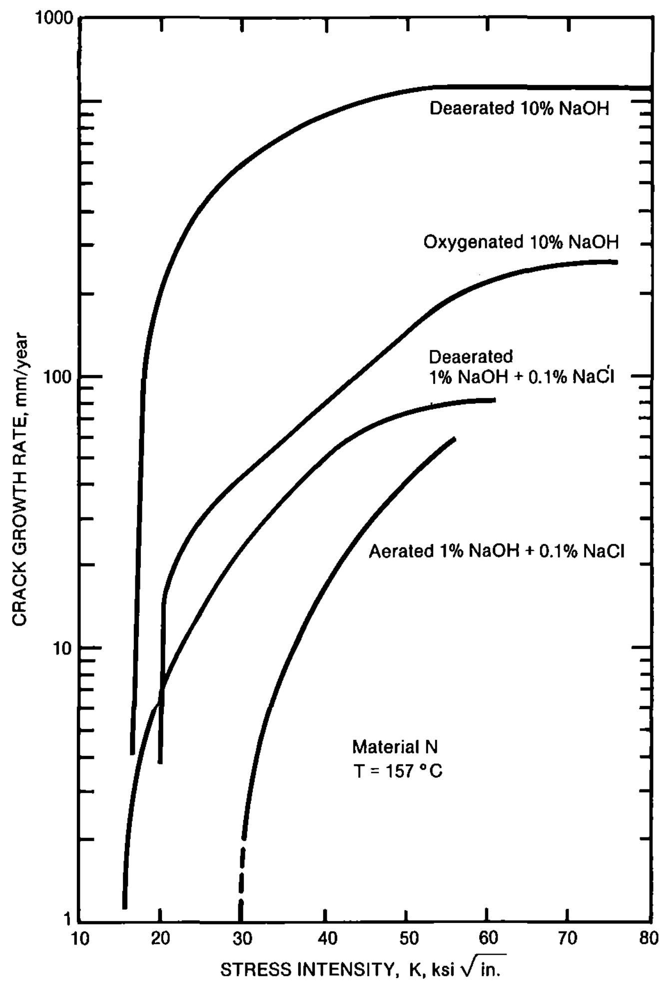
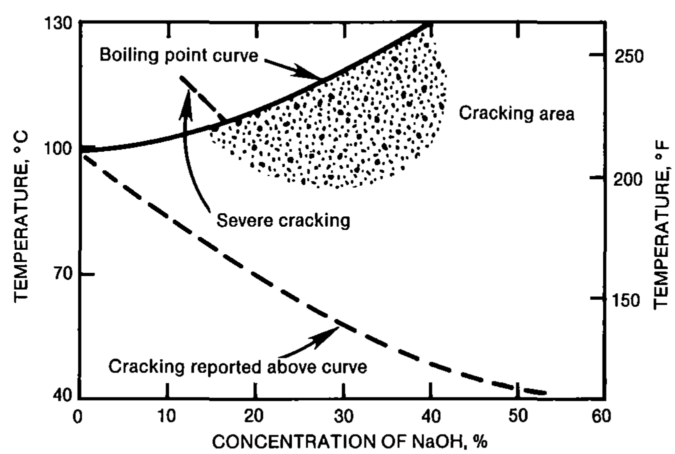
ACI CF-8. Isocorrosion diagram for ACI CF-8 in sodium hydroxide solutions. (a) Test performed in a closed container at equilibrium pressure. (b) Tested at atmospheric pressure. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 579.



Steel. Typical crack growth data for 3.5Ni-1.7Cr-0.4Mo steel. Source: A. McMinn, F.F. Lyle, *et al.*, "Stress Corrosion Crack Growth in NiCr-MoV Turbine Disc Steels," *Corrosion*, Vol 41, Sept 1985, 493.



Steel. Temperature and concentration of sodium hydroxide required to cause cracking of steel. Source: H.W. Schmidt, P.J. Gegner, G. Heinemann, C.F. Pogacar, and E.H. Wyche, *Corrosion*, Vol 7, 1951, 295 and A.A. Berk and W.F. Waldeck, *Chemical Engineering*, Vol 57 (No. 6), 1950, 235.

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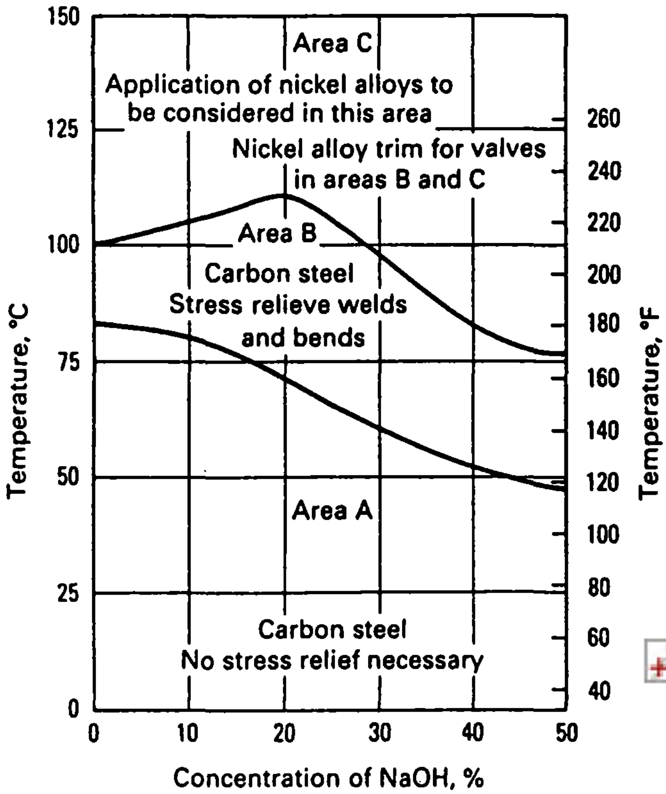

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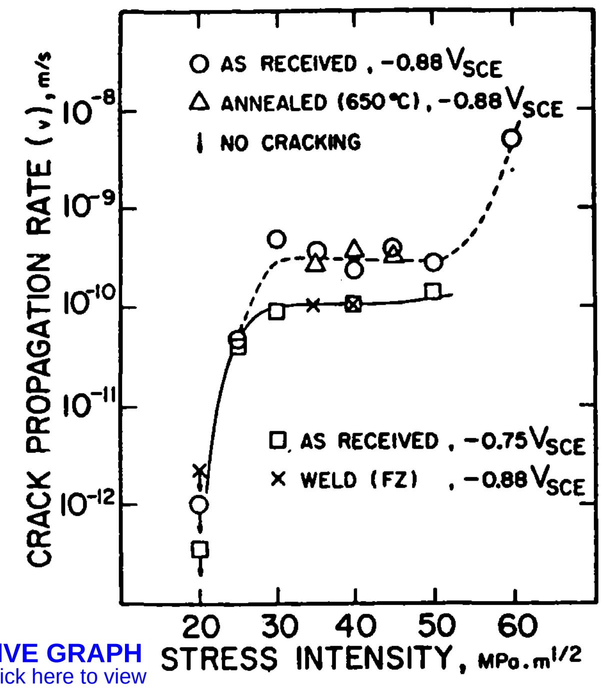
Carbon steels. Temperature and concentration limits for stress-corrosion cracking susceptibility of carbon steels in caustic soda. Source: Corrosion Data Survey — Metals Selection, 6th ed., National Association of Corrosion Engineers, Houston, 1985, 176.



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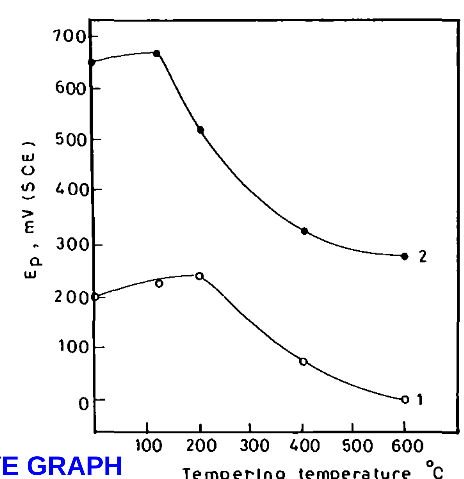
ASTM A516 steel. Effect of stress intensity and potential on stress-corrosion crack propagation in 3.35*m* sodium hydroxide and 0.42*m* sodium sulfide at 92 °C. Source: D. Tromans, E.G. Hawbolt, *et al.*, "Stress Corrosion Cracking of ASTM A516 Steel in Hot Caustic Sulfide Solutions: Potential and Weld Effects," *Corrosion*, Vol 42, Feb 1986, 66.



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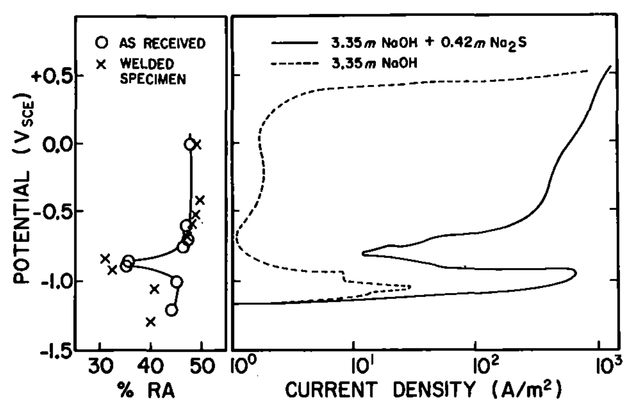
Carbon steels. Dependence of the pitting corrosion potential on the tempering temperature. Curve 1: 0.01*M* sodium hydroxide and 0.01*M* sodium chloride. Curve 2: 0.1*M* sodium hydroxide and 0.02*M* sodium chloride. Source: S.M. Abd El-Haleem, S.S. Abd El Rehim, *et al.*, "Anodic Behavior and Pitting Corrosion of Plain Carbon Steel in NaOH Solutions Containing Chlorine Ions," *Surface Coating Technology*, Vol 27, Feb 1986, 172.



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ASTM A516 steel. Effect of electrochemical potential on reduction in area of slow strain rate specimens tested at 92 °C in 3.35*m* sodium hydroxide and 42*m* sodium sulfide. Also shown are anodic polarization curves for the as-received steel in the sulfide solution and 3.35*m* sodium hydroxide at 92 °C. Source: D. Tromans, E.B. Hawbolt, *et al.*, "Stress Corrosion Cracking of ASTM A516 Steel in Hot Caustic Sulfide Solutions: Potential and Weld Effects," *Corrosion*, Vol 42, Feb 1986, 65.

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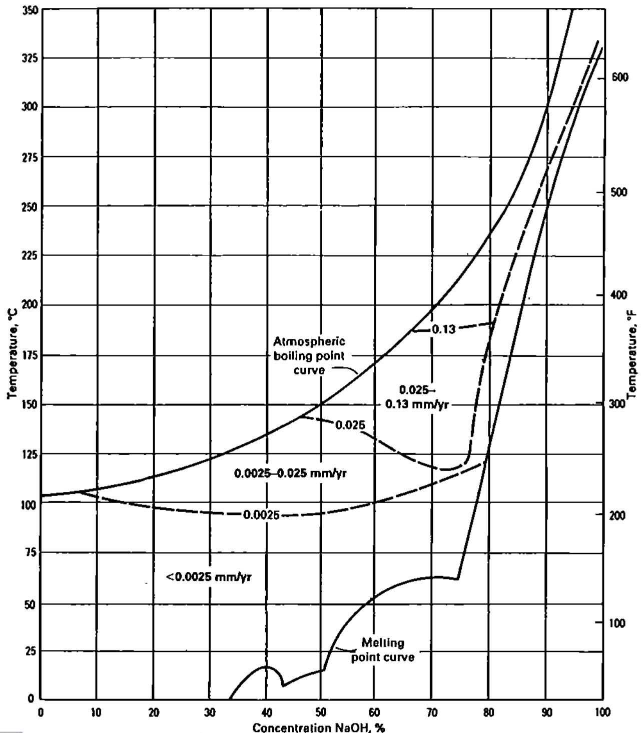

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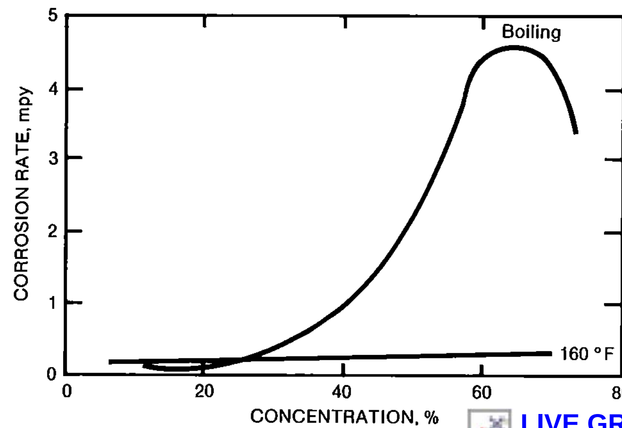
Nickel alloys. Isocorrosion chart for Nickel 200 and Nickel 201 in sodium hydroxide. Only at high caustic concentration near the boiling point does the corrosion rate exceed 1 mil/yr. This isocorrosion chart is intended only as a guide; there are specific conditions under which higher or possibly lower corrosion rates can prevail. Source: "*Corrosion Resistance of Nickel and Nickel-containing Alloys in Caustic Soda and Other Alkalies*," The International Nickel Company, 1973.



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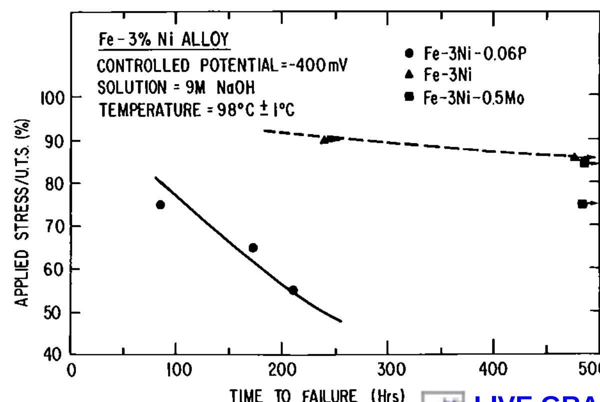
Nickel 270. Corrosion of Nickel 270 in sodium hydroxide. Source: Inco Alloys International, 1979.



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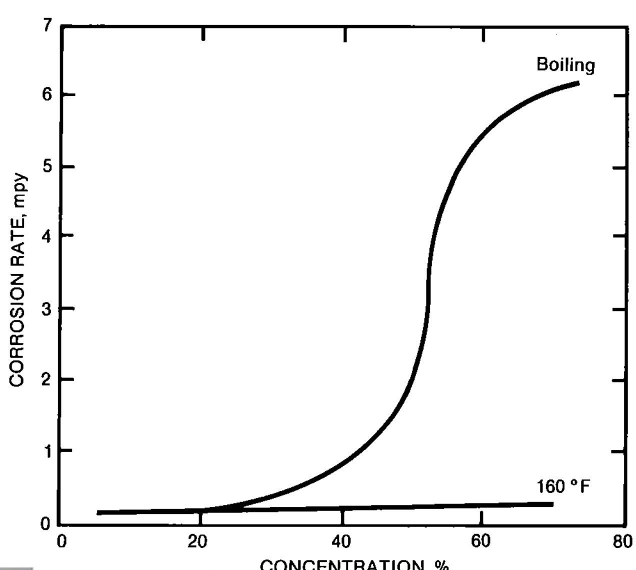
Iron-nickel alloys. Time to failure for various iron-nickel alloys. The vertical axis shows the initial applied stress normalized to the ultimate tensile strength; the horizontal axis shows time to failure. Data points with horizontal arrows indicate that the test was stopped at the time indicated with no failure having occurred. Source: N. Bandyopadhay and C.L. Briant, "Caustic Stress Corrosion Cracking of Low Alloy Iron Base Materials," *Corrosion*, Vol 41, May 1985, 275.



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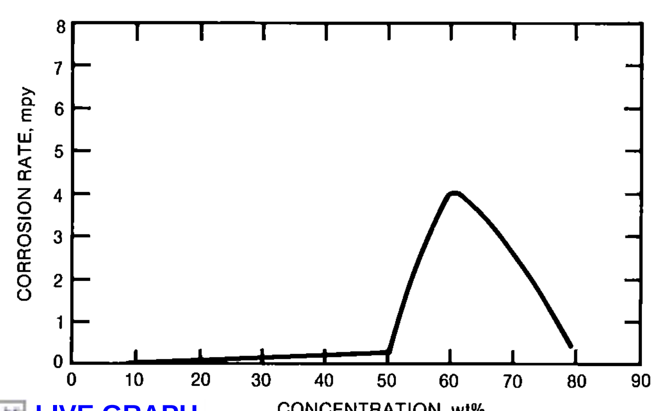
Nickel 201. Corrosion of Nickel 201 in sodium hydroxide. Source: Inco Alloys International, 1979.



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Inconel 600. Corrosion rates in boiling sodium hydroxide. Source: Inco Alloys International, 1962.

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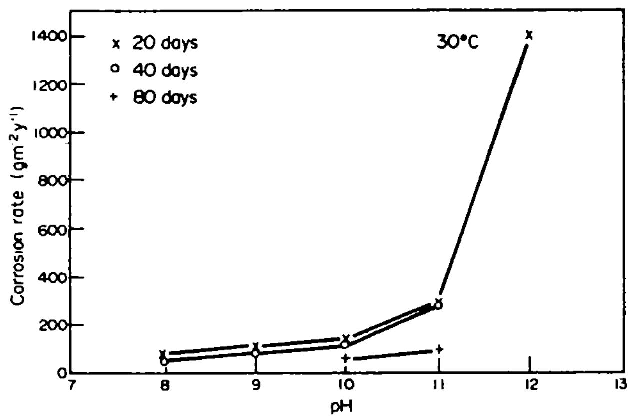

Aluminum. The variation of corrosion rate of aluminum with solution pH at 30 °C (86 °F). Ref. 202

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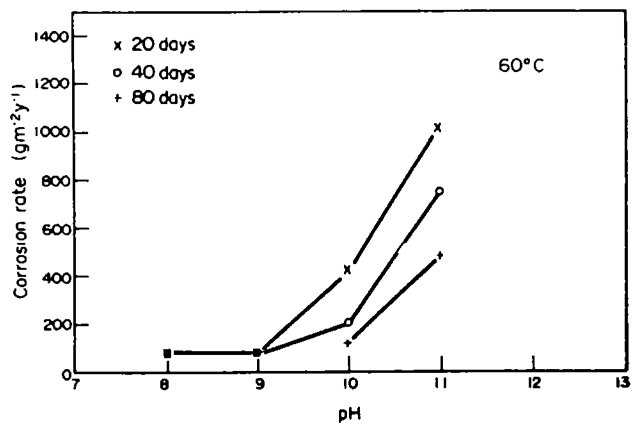

Aluminum. The variation of corrosion rate of aluminum with solution pH at 60 °C (140 °F). Ref. 202

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Sodium Hypochlorite

Sodium hypochlorite, NaOCl, is an air-unstable, pale green crystalline solid that is soluble in cold water, decomposes in hot water, and has a sweet aroma. It generally is available in one of two strengths. The household liquid bleach contains about 5.25 wt% NaClO. The commercial product (sometimes called 15% bleach) contains 150 g/L available chlorine. This is equivalent to about 13 wt% sodium hypochlorite. Sodium hypochlorite is used as a bleaching agent for paper pulp and textiles, as an oxidizing reagent, as a disinfectant, as a chemical intermediate, and in medicines.

The hypochlorite ion (OCl^-) is similar to wet chlorine gas in its effects on materials. Not many metals exhibit good resistance even at low temperatures and concentrations. Because hypochlorite solutions are unstable at neutral and lower pHs, they normally contain excess alkali, which modifies the aggressiveness somewhat.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Some of the newer super stainless steel materials exhibit useful resistance in certain sodium hypochlorite solutions. Successful performance of a high-alloy duplex stainless steel (Ferralium Alloy 255) in a sodium hypochlorite scrubber was recently reported. When stainless steels are attacked in sodium hypochlorite, the mode is usually pitting and/or crevice corrosion.

Aluminum. Generally, hypochlorites promptly destroy the protective oxide films on aluminum and aluminum alloys and cause rapid attack. In laboratory tests, aqueous solutions of sodium hypochlorite caused corrosion that varied with concentration. Alloy 1100 was resistant to dilute solutions of sodium hypochlorite at ambient temperature, whereas more concentrated solutions were very corrosive. Silicates have been used as inhibitors for corrosion of aluminum alloys by sodium hypochlorite.

Copper. In sodium hypochlorite, copper is normally attacked by localized pitting, with corrosion rates exceeding 0.5 mm/yr (20 mils/yr).

Nickel. Nickel and some nickel alloys can be protected from corrosion by sodium hypochlorite by the use of alkaline inhibitors, such as Na_2SiO_3 and Na_3PO_4. The corrosion rates are significantly reduced, and the mode of corrosion becomes more uniform. However, nickel finds few successful applications in sodium hypochlorite service, contrary to its dominance in sodium hydroxide.

Wrought and cast nickel-base iron-chromium-molybdenum alloys (Hastelloy Alloy C-276 wrought, Chlorimet 3, for example) exhibit good resistance in various solutions. The high iron-chromium-nickel alloys such as 20Cb-3 have also been used, especially as pump materials, in less aggressive environments. Many of these materials have shown unpredictable performance in seemingly similar applications.

Osmium. Osmium is dissolved fairly rapidly in sodium hypochlorite at room temperature.

Rhodium. Rhodium, although resistant to corrosion by nearly all aqueous solutions at room temperature, is slowly attacked by solutions of sodium hypochlorite.

Ruthenium. Ruthenium is attacked fairly rapidly by sodium hypochlorite.

Tantalum. Tantalum is very resistant to sodium hypochlorite, but its use is limited because of its relatively high cost.

Titanium. Titanium is the only metal that provides consistently good performance in sodium hypochlorite. Although special titanium alloys are available, the commercial grade 2 is usually suitable for a full range of concentrations and temperatures. Although titanium has been known to suffer crevice corrosion in hot wet chlorine, it apparently has not shown the same susceptibility in hypochlorite solutions. A wide variety of titanium products are used, including piping, pumps, valves, heat exchangers, fans, and vessels.

Corrosion Behavior of Various Metals and Alloys in Sodium Hypochlorite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
2Mo-0.4Cu Stainless steel	...	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.00025 (0.01)	...	45
Low carbon steel	G10100	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	5 (200) min	...	46
Low carbon steel	G10100	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.025 (1.0)	...	45
Copper and alloys									
70-30 cupronickel	C71500	...	Place of a copper metal	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	Than corrosion	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Iron and alloys									
Durachlor	...	...	Repeated exposures	16	20 (70)	170 d	0.02 (0.8)	...	3
Durichlor	...	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	0.18 (7)	...	46
Duriron	F47003	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	0.3 (12)	...	46
Miscellaneous									
Iridium	...	...	Plus NaCl	Saturated	100 (212)	...	0.25 (10) max	...	18
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	0.10 (4)	...	12
Osmium	...	...	Plus NaCl	Saturated	Room	...	Poor	...	26
Palladium	P03980	...	Plus NaCl	Saturated	Room	...	1.8 (71)	...	17
Palladium	P03980	...	Plus NaCl	Saturated	100 (212)	...	14.9 (587)	...	17
Platinum	P04995	...	...	All	100 (212)	...	0.05 (2) max	...	5
Rhodium	P05990	...	Plus NaCl	Saturated	Room	...	0.25 (10) max	...	29
Ruthenium	...	...	Plus NaCl	Saturated	100 (212)	...	Questionable	...	18
Ruthenium	...	...	Plus NaCl, saturated solution	Saturated	100 (212)	...	Questionable	...	18
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	9
Silver	P07010	...	Plus NaCl	Saturated	Room	...	0.05 (2) max	...	9

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel and alloys									
Chlorimet 3	...	...	Repeated exposures	16	20 (70)	170 d	0.008 (0.3)	...	3
Hastelloy C	...	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	1.2 (46)	...	46
Hastelloy C	...	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.005 (0.2)	...	45
Hastelloy C	...	...	Repeated exposures	16	20 (70)	170 d	0.003 (0.1)	...	3
Incoloy 800	N08800	Cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	...	1	80 (176)	42 d	0.13 (5.0)	Pitting	44
Incoloy 800	N08800	Test specimens were cold-rolled, annealed sheet, 2.84 mm (0.112 in.) thick	...	5	80 (176)	42 d	0.20 (8.0)	Pitting	44
Incoloy 825	N08825	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.005 (0.2)	...	45
Inconel 600	N06600	...	Beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.3 (12)	...	118
Inconel 600	N06600	...	Beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.13 (5)	...	118
Inconel 600	N06600	...	Beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.05 (2)	...	118
Inconel 600	N06600	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.005 (0.02)	...	45
Inconel 600	N06600	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.08 (3)	...	118
Inconel 600	N06600	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.025 (1)	...	118
Inconel 600	N06600	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.02 (0.7)	...	118
Inconel 600	N06600	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.025 (1)	...	118
Inconel 600	N06600	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.02 (0.7)	...	118
Inconel 600	N06600	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation.	6.5 g/L	40 (105)	16 h	0.08 (3)	...	118
Inconel 600	N06600	...	Plus 2.0 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.025 (1)	...	118
Inconel 600	N06600	...	Plus 2.0 g/L Na_3PO_4, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.025 (1)	...	118
Inconel 601	N06601	...	...	1	80 (176)	7 d	0.09 (3.5)	Pitting	64
Inconel 601	N06601	...	...	5	80 (176)	7 d	0.175 (6.9)	Pitting	64
Monel 400	N04400	...	Beaker test, no agitation	6.5 g/L	40 (105)	16 h	2.9 (113)	...	118
Monel 400	N04400	...	Beaker test, no agitation	3.3 g/L	40 (105)	16 h	1.0 (40)	...	118
Monel 400	N04400	...	Beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.1 (4)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.46 (18)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.025 (1)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.008 (0.3)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.2 (8)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.1 (4)	...	118
Monel 400	N04400	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.033 (1.3)	...	118

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel 400	N04400	...	Plus 2.0 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.05 (2)	...	118
Monel 400	N04400	...	Plus 2.0 g/L Na_3PO_4, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.08 (3)	...	118
Nickel 200	N02200	...	100 ppm available chlorine	...	25 (77)	...	0.008 (0.3)	...	44
Nickel 200	N02200	...	35 ppm available chlorine	...	25 (77)	...	0.003 (0.1)	...	44
Nickel 200	N02200	...	500 ppm available chlorine	...	25 (77)	...	0.02 (0.8)	...	44
Nickel 200	N02200	...	Beaker test, no agitation	6.5 g/L	40 (105)	16 h	1.3 (52)	...	118
Nickel 200	N02200	...	Beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.8 (30)	...	118
Nickel 200	N02200	...	Beaker test, no agitation.	0.1 g/L	40 (105)	16 h	0.1 (4)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.25 (10)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.1 (4)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_2SiO_3, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.013 (0.5)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.5 (20)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	3.3 g/L	40 (105)	16 h	0.15 (6)	...	118
Nickel 200	N02200	...	Plus 0.5 g/L Na_3PO_4, beaker test, no agitation	0.1 g/L	40 (105)	16 h	0.015 (0.6)	...	118
Nickel 200	N02200	...	Plus 2.0 g/L Na_2SiO_3, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.025 (1)	...	118
Nickel 200	N02200	...	Plus 2.0 g/L Na_3PO_4, beaker test, no agitation	6.5 g/L	40 (105)	16 h	0.23 (9)	...	118
Refractory metals and alloys									
Niobium	R04210	...	...	6	50 (120)	...	1.3 (50)	...	2
Titanium	...	...	...	6	Room	...	Resistant	...	90
Titanium	...	...	...	6	25 (77)	...	Resistant	...	27
Titanium	...	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	0.003 (0.1)	...	46
Titanium	...	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.003 (0.1) max	...	45
Titanium	...	...	Plus 15% NaCl + 1% NaOH	1.5-4	66-93 (151-200)	...	0.030 (1.2)	...	90
Titanium	...	...	Repeated exposures	16	20 (70)	170 d	0.03 (0.1) max	...	3
Zirconium	R60701	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	0.1 (4)	...	46
Zirconium	R60701	...	Repeated exposures	16	20 (70)	170 d	0.003 (0.1) max	...	3
Zr702	R60702	...	...	6	100 (212)	...	0.13 (5) max	...	15
Zr702	R60702	...	...	6	50 (120)	...	Resistant	...	15
Zr705	R60705	...	...	6	50 (120)	...	Resistant	...	15
Stainless steels									
301	S30100	...	...	50	20 (68)	...	Good	Pitting	253
301	S30100	...	...	...	Boiling	...	Good	Pitting	253
302	S30200	...	...	50	20 (68)	...	Good	Pitting	253
302	S30200	...	...	...	Boiling	...	Good	Pitting	253
303	S30300	...	...	50	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	50	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Good	Pitting	253
304	S30400	...	...	50	20 (68)	...	Good	Pitting	253
304	S30400	...	...	...	Boiling	...	Good	Pitting	253
304	S30400	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.025 (1.0)	...	45
304L	S30403	...	...	50	20 (68)	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Hypochlorite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	...	Boiling	...	Good	Pitting	253
304LN	S30453	...	...	50	20 (68)	...	Good	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	...	50	20 (68)	...	Good	Pitting	253
316	S31600	...	...	...	Boiling	...	Good	Pitting	253
316	S31600	...	In 1.5 to 4% NaOCl with 12-15% NaCl and 1% NaOH	...	65-95 (150-200)	72 d	2.5 (100) min	...	46
316	S31600	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.008 (0.3)	...	45
316F	S31620	...	...	50	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	...	Boiling	...	Good	Pitting	253
316L	S31603	...	...	50	20 (68)	...	Good	Pitting	253
316L	S31603	...	...	...	Boiling	...	Good	Pitting	253
316LN	S31653	...	...	50	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Good	Pitting	253
316Ti	S31635	...	...	50	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Good	Pitting	253
317	S31700	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.00025 (0.01)	...	45
317L	S31703	...	...	50	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	...	Boiling	...	Good	Pitting	253
317LN	S31725	...	...	50	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Good	Pitting	253
321	S32100	...	...	50	20 (68)	...	Good	Pitting	253
321	S32100	...	...	...	Boiling	...	Good	Pitting	253
329	S32900	...	...	50	20 (68)	...	Good	Pitting	253
329	S32900	...	...	...	Boiling	...	Good	Pitting	253
347	S34700	...	...	50	20 (68)	...	Good	Pitting	253
347	S34700	...	...	...	Boiling	...	Good	Pitting	253
403	S40300	...	...	50	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	50	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	50	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	Room	...	Poor	...	121
410	S41000	...	...	50	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	Slight alkaline	Saturated	0-93 (0-200)	...	Good	...	121
416	S41600	...	...	50	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	50	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	50	20 (68)	...	Questionable	Pitting	253
430	S43000	...	...	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	50	20 (68)	...	Questionable	Pitting	253
434	S43400	...	...	...	Boiling	...	Questionable	Pitting	253
E-Brite	S44627	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.003 (0.1) max	...	45
F51	S31803	...	...	50	20 (68)	...	Good	Pitting	253
F51	S31803	...	...	...	Boiling	...	Good	Pitting	253
Remanit 2800	...	...	NaOCl solution (pH 9) with 500 ppm active chlorine and 1.2% NaCl	...	50 (120)	...	0.000025 (0.001)	...	45

Sodium Nitrate

Sodium nitrate, $NaNO_3$, also known as soda niter and Chile saltpeter, is a fire-hazardous, transparent, colorless and odorless crystalline solid. It is soluble in glycerol and water, decomposes when heated, and melts at 308 °C (585 °F). Sodium nitrate is used in making nitric and sulfuric acids, in the manufacture of glass and pottery enamel, as a fertilizer, as a food preservative, in explosives, and as a welding flux.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 was resistant to solid sodium nitrate in laboratory tests conducted under conditions of 100% relative humidity at ambient temperature. In other laboratory tests, alloy 1100 was resistant to aqueous solutions of sodium nitrate (0.1 to 43%) at ambient temperature. Sodium nitrate has been used in combination with sodium nitrite as an inhibitor to retard the corrosion of aluminum alloys.

Copper. Transgranular cracking was observed on specimens of copper alloy C44300 immersed in naturally aerated 1*N* sodium nitrate at pH 8 and a potential of 0.15 V versus standard hydrogen electrode (SHE). The fracture test relative to air was 0.34.

Copper alloy (Cu-23Zn-12Ni) wires measuring 0.6 mm (0.023 in.) in diameter and normally under a 6-g load and positive potential in telephone equipment were observed to undergo stress-corrosion cracking within 2 years. Laboratory tests suggested that nitrate salts were the cause. Wires of Cu-20Ni did not crack under similar conditions.

Corrosion Behavior of Various Metals and Alloys in Sodium Nitrate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Lead	L50045	...	...	10	24 (75)	...	71.3 (50) min	...	95
Lead (99.999%)	L50001	...	...	0.9	75 (167)	60 d	.49 (19.3)	...	208
Lead (99.999%)	L50001	...	...	0.09	75 (167)	60 d	.52 (20.5)	...	208

(Continued)

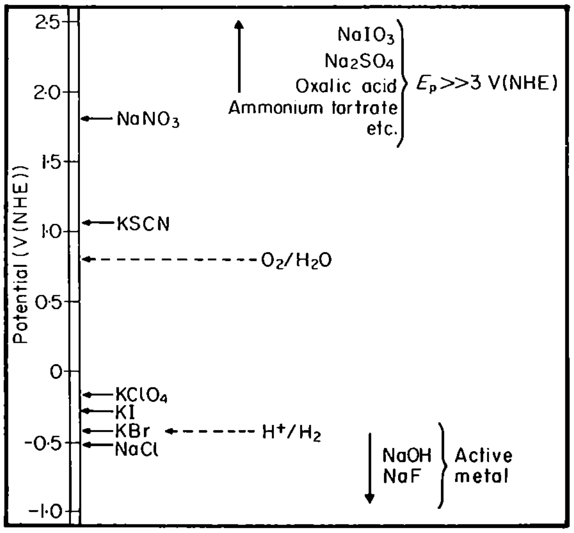
Corrosion Behavior of Various Metals and Alloys in Sodium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead (99.999%)	L50001	...	...	0.009	75 (167)	60 d	.39 (15.4)	...	208
Lead (99.999%)	L50001	...	...	0.09	20 (68)	60 d	.002 (0.1)	...	208
Platnium	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Resistant	...	94
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
301	S30100	...	...	Fused	360 (680)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	Fused	360 (680)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	Fused	360 (680)	...	Resistant	...	253
303	S30300	...	...	Fused	360 (680)	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	Fused	360 (680)	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Plus crude sodium-nitrate solution (evaporator)	~12-68	111 (232)	30 d	0.02 (0.7)	Severe pitting	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	Fused	360 (680)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Fused	360 (680)	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	Fused	360 (680)	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Plus crude sodium-nitrate solution (evaporator)	~12-68	111 (232)	30 d	0.02 (0.6)	...	89
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	Fused	360 (680)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	Fused	360 (680)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Fused	360 (680)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253

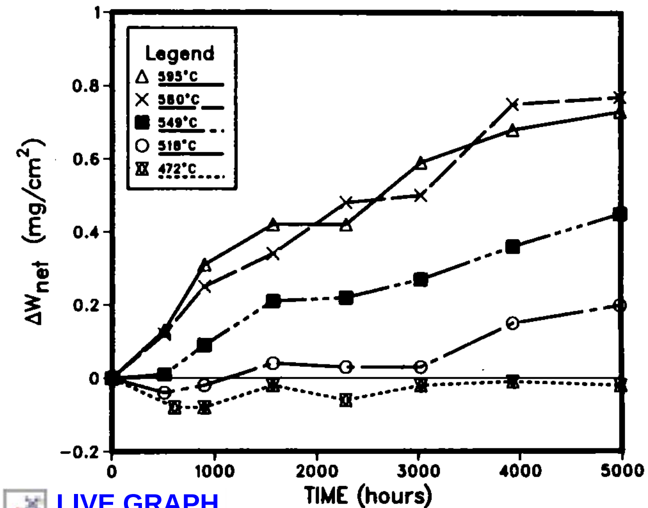
(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Nitrate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Fused	360 (680)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	Fused	360 (680)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Fused	360 (680)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	Fused	360 (680)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	Fused	360 (680)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	Fused	360 (680)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	Fused	360 (680)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	Fused	360 (680)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	Fused	360 (680)	...	Resistant	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	Fused	360 (680)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	Fused	360 (680)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	Fused	360 (680)	...	Resistant	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	Fused	360 (680)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	Fused	360 (680)	...	Resistant	...	253
Carpenter 20	...	...	No aeration; rapid agitation. Plus crude sodium-nitrate solution (evaporator)	~12-68	111 (232)	30 d	.015 (0.6)	Severe pitting	89
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	Fused	360 (680)	...	Resistant	...	253



Aluminum. Pitting potentials of aluminum in various electrolytes. Solutions of 1*M* concentration were used, except for $KClO_4$, for which a 0.1*M* solution was used. The standard potentials for hydrogen evolution and for oxygen reduction in neutral solutions have been included as a reference. Source: J.R. Galvele, Pitting Corrosion, in *Treatise on Materials Science and Technology*, Vol 23, J.C. Scully, Ed., Academic Press, New York, 1983, 16.



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Incoloy 800. Net weight changes vs. time for Incoloy 800 exposed at various temperatures to 60% $NaNO_3$ + 40% KNO_3. Source: R.W. Bradshaw, "Thermal Convection Loop Study of the Corrosion of Incoloy 800 in Molten $NaNO_3/KNO_3$," *Corrosion*, Vol 43, Mar 1987, 174.

Sodium Nitrite

Sodium nitrite, $NaNO_2$, is a fire-hazardous, air-sensitive, yellowish-white powder that is soluble in water and decomposes at temperatures above 320 °C (608 °F). Sodium nitrite is used as an intermediate for dyestuffs and for pickling of meat, in dyeing of textiles, in rustproofing, in medicine, and as a reagent in organic chemistry.

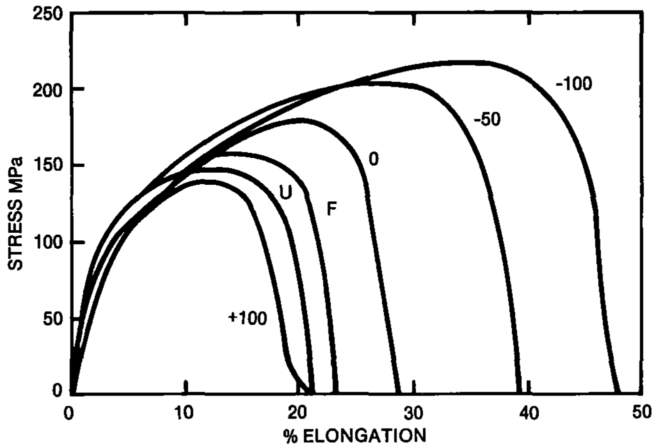
Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Copper, 99.9 and 99.996% pure, exhibited transgranular cracking when subjected to a strain rate of 10^{-6} s^{-1} while immersed in 1*M* sodium nitrite at a pH of 8.2. The 99.9% copper tested in solution exhibited an ultimate tensile strength of 160 MPa (23 ksi) and 25% elongation, as opposed to the 196 MPa (28.5 ksi) and 55% elongation obtained in air. Cracking in 1*M* sodium nitrite was also observed in alloy C26000, in admiralty brasses, and in alloy C70600.

Corrosion Behavior of Various Metals and Alloys in Sodium Nitrite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Mild steel	G10100	...	Rotating bottle tests using pipeline water, pH 9, and regular gasoline	0.0	Room	14 d	0.07 (2.8)	...	140
Mild steel	G10100	...	Rotating bottle tests using pipeline water, pH 9, and regular gasoline	0.02	Room	14 d	0.05 (2.0)	...	140
Mild steel	G10100	...	Rotating bottle tests using pipeline water, pH 9, and regular gasoline	0.04	Room	14 d	0.01 (0.5)	...	140
Mild steel	G10100	...	Rotating bottle tests using pipeline water, pH 9, and regular gasoline	0.06	Room	14 d	0.0 (0.0)	...	140
Mild steel	G10100	...	Rotating bottle tests using pipeline water, pH 9, and regular gasoline	0.10	Room	14 d	0.0 (0.0)	...	140
Miscellaneous									
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	1.0 (40)	...	12
Stainless steels									
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	Textile processing; no aeration; rapid agitation. Plus 0.9% sodium chloride, diazoting bath	0.3-0.4	82 (180)	0.2 d	0.14 (5.6)	...	89
304	S30400	...	Textile processing; no aeration; rapid agitation; low-carbon grade specimens (0.03% C max). Plus 0.9% sodium chloride, diazoting bath	0.3-0.4	82 (180)	0.2 d	0.15 (5.8)	...	89
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	Textile processing; no aeration; rapid agitation. Plus 0.9% sodium chloride, diazoting bath	0.3-0.4	82 (180)	0.2 d	0.11 (4.4)	...	89
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253



Copper. Stress-elongation curves obtained from slow strain rate testing of copper (Cu-OF) in aerated 0.6*M* sodium nitrite solution at room temperature. The figures on the curves indicate applied potential in mV, saturated calomel electrode (SCE); F = free corrosion potential, and U = +50 mV; the strain rate = 2.6 x 10^{-6} s^{-1}. Source: E. Mattisson, "Focus on Copper in Modern Corrosion Research," *Materials Performance*, Vol 26, April 1987, 15.

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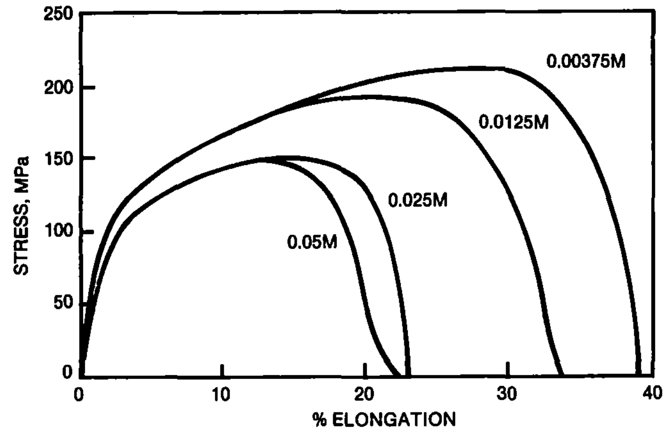

Copper. Stress-elongation curves obtained from slow strain rate testing of copper (Cu-OF) in aerated solutions of sodium nitrite at room temperature and an electrode potential of +100 mV (SCE) at a strain rate of 2.6 x 10^{-6} s^{-1}. Source: E. Mattisson, "Focus on Copper in Modern Corrosion Research," *Materials Performance*, Vol 26, April 1987, 15.

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Sodium Perborate

Sodium perborate, anhydrous, $NaBO_3$ is a white, amorphous powder of unknown constitution containing active oxygen that evolves oxygen gas when dissolved in water, and is hygroscopic. Derived by heating sodium perborate tetrahydrate. Used as a denture cleaner and oxygen source.

Sodium perborate, monohydrate, $NaBO_3{\cdot}H_2O$, better represented as $Na_2(B_2(O_2)_2(OH)_4)$ is a white, amorphous powder that is rapidly soluble in water giving a solution of H_2O_2 and sodium borated. Derived by partial dehydration of sodium perborate tetrahydrate. Used as a denture cleaner and bleaching agent.

Corrosion Behavior of Various Metals and Alloys in Sodium Perborate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253

Sodium Perchlorate

Sodium perchlorate, $NaClO_4$, is a flammable, white crystalline deliquescent solid that melts at 482 °C (899.6 °F). Soluble in water and alcohol, it is used as an analytical reagent. Sodium perchlorate is explosive in nature when in contact with concentrated sulfuric acid and finds use in explosives and jet fuels.

Corrosion Behavior of Various Metals and Alloys in Sodium Perchlorate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Gold	P00016	...	Melt	...	480 (900)	...	Poor	...	9
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	480 (900)	...	Poor	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Refractory metals and alloys									
Titanium	...	...	...	900 g/L	50 (122)	...	0.003 (0.12)	...	90
Stainless steels									
301	S30100	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
409	S40900	...	...	10	Boiling	...	Questionable	...	253
410	S41000	...	...	10	Boiling	...	Questionable	...	253
416	S41600	...	...	10	Boiling	...	Questionable	...	253
420	S42000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	10	Boiling	...	Good	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253

Sodium Peroxide

Sodium peroxide, Na_2O_2, is a fire-hazardous white powder that yellows when heated and causes ignition when in contact with water. Sodium peroxide is decomposed by heating, although this is not easily accomplished. It is stable in dry air; however, in moist air, or when acted on by water, it decomposes readily. It can be a powerful oxidizer and a powerful reducing agent, depending on conditions. Sodium peroxide is also used as a bleach, in medicine soap, and in the decomposition of minerals.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Solid sodium peroxide was very corrosive to alloys 3003 and 5154 in laboratory tests under conditions of 100% relative humidity at ambient temperature.

Ruthenium. Ruthenium is attacked rapidly by fused sodium peroxide.

Corrosion Behavior of Various Metals and Alloys in Sodium Peroxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	400 (750)	...	0.05 (2) max	...	5
Silver	P07010	...	Melt	...	400 (750)	...	Poor	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Resistant	...	94
Refractory metals and alloys									
Zr702	R60702	...	...	0-100	Room to 100 (212)	...	0.025 (2) max	...	15
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Peroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Good	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Questionable	...	253
303	S30300	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Peroxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
403	S40300	...	...	10	20 (68)	...	Questionable	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
405	S40500	...	...	10	20 (68)	...	Questionable	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
409	S40900	...	...	10	20 (68)	...	Questionable	...	253
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
410	S41000	...	...	10	20 (68)	...	Questionable	...	253
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
416	S41600	...	...	10	20 (68)	...	Questionable	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
420	S42000	...	...	10	20 (68)	...	Questionable	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Poor	...	253
430	S43000	...	...	10	20 (68)	...	Good	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Questionable	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	Stabilized with sodium silicate	10	Up to 80° (176°)	...	Resistant	...	253

Sodium Phosphate

This is a general term encompassing the following compounds: sodium hexametaphosphate, sodium metaphosphate, dibasic sodium phosphate, hemibasic sodium phosphate, monobasic sodium phosphate, tribasic sodium phosphate, sodium pyrophosphate, and acid sodium phosphate.

Corrosion Behavior of Various Metals and Alloys in Sodium Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Secondary	...	20 (68)	...	Resistant	...	253
301	S30100	...	Secondary	...	Boiling	...	Resistant	...	253
301	S30100	...	Tertiary	...	20 (68)	...	Resistant	...	253
301	S30100	...	Tertiary	...	Boiling	...	Resistant	...	253
302	S30200	...	Secondary	...	20 (68)	...	Resistant	...	253
302	S30200	...	Secondary	...	Boiling	...	Resistant	...	253
302	S30200	...	Tertiary	...	20 (68)	...	Resistant	...	253
302	S30200	...	Tertiary	...	Boiling	...	Resistant	...	253
303	S30300	...	Secondary	...	20 (68)	...	Resistant	...	253
303	S30300	...	Secondary	...	Boiling	...	Resistant	...	253
303	S30300	...	Secondary	...	20 (68)	...	Resistant	...	253
303	S30300	...	Secondary	...	Boiling	...	Resistant	...	253
303	S30300	...	Tertiary	...	20 (68)	...	Resistant	...	253
303	S30300	...	Tertiary	...	Boiling	...	Resistant	...	253
303	S30300	...	Tertiary	...	20 (68)	...	Resistant	...	253
303	S30300	...	Tertiary	...	Boiling	...	Resistant	...	253
304	S30400	...	Secondary	...	20 (68)	...	Resistant	...	253
304	S30400	...	Secondary	...	Boiling	...	Resistant	...	253
304	S30400	...	Tertiary	...	20 (68)	...	Resistant	...	253
304	S30400	...	Tertiary	...	Boiling	...	Resistant	...	253
304L	S30403	...	Secondary	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Secondary	...	Boiling	...	Resistant	...	253
304L	S30403	...	Tertiary	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Tertiary	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Secondary	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Secondary	...	Boiling	...	Resistant	...	253
304LN	S30453	...	Tertiary	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Tertiary	...	Boiling	...	Resistant	...	253
316	S31600	...	Secondary	...	20 (68)	...	Resistant	...	253
316	S31600	...	Secondary	...	Boiling	...	Resistant	...	253
316	S31600	...	Tertiary	...	20 (68)	...	Resistant	...	253
316	S31600	...	Tertiary	...	Boiling	...	Resistant	...	253
316F	S31620	...	Secondary	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Secondary	...	Boiling	...	Resistant	...	253
316F	S31620	...	Tertiary	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Tertiary	...	Boiling	...	Resistant	...	253
316L	S31603	...	Secondary	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Secondary	...	Boiling	...	Resistant	...	253
316L	S31603	...	Tertiary	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Tertiary	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Secondary	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Secondary	...	Boiling	...	Resistant	...	253
316LN	S31653	...	Tertiary	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Tertiary	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Secondary	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Secondary	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	Tertiary	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Tertiary	...	Boiling	...	Resistant	...	253
317L	S31703	...	Secondary	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Secondary	...	Boiling	...	Resistant	...	253
317L	S31703	...	Tertiary	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Tertiary	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Phosphate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	Secondary	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Secondary	...	Boiling	...	Resistant	...	253
317LN	S31725	...	Tertiary	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Tertiary	...	Boiling	...	Resistant	...	253
321	S32100	...	Secondary	...	20 (68)	...	Resistant	...	253
321	S32100	...	Secondary	...	Boiling	...	Resistant	...	253
321	S32100	...	Tertiary	...	20 (68)	...	Resistant	...	253
321	S32100	...	Tertiary	...	Boiling	...	Resistant	...	253
329	S32900	...	Secondary	...	20 (68)	...	Resistant	...	253
329	S32900	...	Secondary	...	Boiling	...	Resistant	...	253
329	S32900	...	Tertiary	...	20 (68)	...	Resistant	...	253
329	S32900	...	Tertiary	...	Boiling	...	Resistant	...	253
347	S34700	...	Secondary	...	20 (68)	...	Resistant	...	253
347	S34700	...	Secondary	...	Boiling	...	Resistant	...	253
347	S34700	...	Tertiary	...	20 (68)	...	Resistant	...	253
347	S34700	...	Tertiary	...	Boiling	...	Resistant	...	253
403	S40300	...	Secondary	...	20 (68)	...	Resistant	...	253
403	S40300	...	Secondary	...	Boiling	...	Resistant	...	253
403	S40300	...	Tertiary	...	20 (68)	...	Resistant	...	253
403	S40300	...	Tertiary	...	Boiling	...	Resistant	...	253
405	S40500	...	Secondary	...	20 (68)	...	Resistant	...	253
405	S40500	...	Secondary	...	Boiling	...	Resistant	...	253
405	S40500	...	Tertiary	...	20 (68)	...	Resistant	...	253
405	S40500	...	Tertiary	...	Boiling	...	Resistant	...	253
409	S40900	...	Secondary	...	20 (68)	...	Resistant	...	253
409	S40900	...	Secondary	...	Boiling	...	Resistant	...	253
409	S40900	...	Tertiary	...	20 (68)	...	Resistant	...	253
409	S40900	...	Tertiary	...	Boiling	...	Resistant	...	253
410	S41000	...	Secondary	...	20 (68)	...	Resistant	...	253
410	S41000	...	Secondary	...	Boiling	...	Resistant	...	253
410	S41000	...	Tertiary	...	20 (68)	...	Resistant	...	253
410	S41000	...	Tertiary	...	Boiling	...	Resistant	...	253
416	S41600	...	Secondary	...	20 (68)	...	Resistant	...	253
416	S41600	...	Secondary	...	Boiling	...	Resistant	...	253
416	S41600	...	Tertiary	...	20 (68)	...	Resistant	...	253
416	S41600	...	Tertiary	...	Boiling	...	Resistant	...	253
420	S42000	...	Secondary	...	20 (68)	...	Resistant	...	253
420	S42000	...	Secondary	...	Boiling	...	Resistant	...	253
420	S42000	...	Tertiary	...	20 (68)	...	Resistant	...	253
420	S42000	...	Tertiary	...	Boiling	...	Resistant	...	253
430	S43000	...	Secondary	...	20 (68)	...	Resistant	...	253
430	S43000	...	Secondary	...	Boiling	...	Resistant	...	253
430	S43000	...	Tertiary	...	20 (68)	...	Resistant	...	253
430	S43000	...	Tertiary	...	Boiling	...	Resistant	...	253
434	S43400	...	Secondary	...	20 (68)	...	Resistant	...	253
434	S43400	...	Secondary	...	Boiling	...	Resistant	...	253
434	S43400	...	Tertiary	...	20 (68)	...	Resistant	...	253
434	S43400	...	Tertiary	...	Boiling	...	Resistant	...	253
F51	S31803	...	Secondary	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Secondary	...	Boiling	...	Resistant	...	253
F51	S31803	...	Tertiary	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Tertiary	...	Boiling	...	Resistant	...	253

Sodium p-Toluenesulfochloramin

Also known as chloramine-T—not to be confused with NH_2Cl which is also termed chloramine—$CH_3C_6H_4SO_2NNaCl{\cdot}3H_2O$, is white or slightly yellow crystals or crystalline powder, containing more than 11.5% and less than 13% active chlorine and has a slight odor of chlorine. It decomposes slowly in air, liberating chlorine. Soluble in water, insoluble in benzene, chloroform, and ether, and decomposed by alcohol. Derivation is by reaction of ammonia and p-toluenesulfochloride under pressure. The product is reacted with sodium hypochlorite in the presence of an alkali, and the cloramine produced by crystallization. It is used as a medicine (antiseptic) and reagent.

Corrosion Behavior of Various Metals and Alloys in Sodium p-Toluenesulfochloramin

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Good	...	253
301	S30100	...	...	...	Boiling	...	Good	...	253
302	S30200	...	...	...	20 (68)	...	Good	...	253
302	S30200	...	...	...	Boiling	...	Good	...	253
303	S30300	...	...	...	20 (68)	...	Good	...	253
303	S30300	...	...	...	Boiling	...	Good	...	253
304	S30400	...	...	...	20 (68)	...	Good	...	253
304	S30400	...	...	...	Boiling	...	Good	...	253
304L	S30403	...	...	...	20 (68)	...	Good	...	253
304L	S30403	...	...	...	Boiling	...	Good	...	253
304LN	S30453	...	...	...	20 (68)	...	Good	...	253
304LN	S30453	...	...	...	Boiling	...	Good	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Good	...	253
316F	S31620	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Good	...	253
321	S32100	...	...	...	Boiling	...	Good	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Good	...	253
347	S34700	...	...	...	Boiling	...	Good	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Sodium Salicylate

Sodium salicylate, HOC_6H_4COONa, is a shiny, white powder with sweetish taste and mild aromatic aroma that is soluble in water, glycerol, and alcohol. Used in medicine and as a preservative.

Corrosion Behavior of Various Metals and Alloys in Sodium Salicylate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Sodium Silicate

Sodium silicate, Na_2SiO_3, also known as a liquid glass, silicate of soda, sodium metasilicate, and soluble glass, is a grayish-white crystalline powder that has a melting point of 1088 °C (1990 °F). It is soluble in water and has strong detergent and emulsifying properties. Sodium silicate is used to fireproof textiles, insulate electric wire, protect wood and porous stone, greaseproof paper containers, and as a catalyst in refining high-octane gasoline.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. The resistance to corrosion of aluminum alloys by sodium silicates depends on the weight ratio of SiO_2/Na_2O. Commercial sodium silicates with a weight ratio of 2 have been used as inhibitors of corrosion of aluminum alloys in alkaline solutions. In laboratory tests, sodium metasilicate with a weight ratio of 1 was very corrosive to alloy 1100 at ambient temperature.

Corrosion Behavior of Various Metals and Alloys in Sodium Silicate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Questionable	...	92
Aluminum-silicon alloys	...	...	...	...	...	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Copper nickel	...	...	...	...	...	...	40 (1.5) max	...	76
Copper zinc	...	...	...	...	...	...	125 (5) max	...	76
Copper- tin	...	...	...	...	...	...	50 (2) max	...	76
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel- silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	All	Room	...	Resistant	...	119
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	0.003 (0.1)	...	12
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	0.005	60 (140)	...	0.030 (1.2)	...	75
Tin	...	...	...	0.02	60 (140)	...	0.045 (1.8)	...	75
Tin	...	...	...	0.05	60 (140)	...	Resistant	...	75
Tin	...	...	...	0.10	60 (140)	...	0.015 (0.6)	...	75
Tin	...	...	...	0.15	60 (140)	...	0.08 (3.0)	...	75
Tin	...	...	...	0.20	60 (140)	...	0.09 (3.5)	...	75
Tin	...	...	...	0.25	60 (140)	...	0.12 (4.7)	...	75
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Resistant	...	94
Refractory metals and alloys									
Titanium	...	...	...	25	Boiling	...	Resistant	...	90
Zr702	R60702	...	...	0-100	Room to 100 (212)	...	0.025 (2) max	...	15

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Silicate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Sodium Sulfate

Sodium sulfate, Na_2SO_4, also known as thenardite and salt cake, is a crystalline compound that melts at 888 °C (1632 °F). Sodium sulfate is found in natural form (thenardite) in Chile and Spain. It is used in the manufacture of paperboard, glass, and freezing mixtures. The hydrate, $Na_2SO_4 \cdot 10H_2O$, also known as "Glauber's salt," is a white water-soluble solid formed by heating sodium chloride and sulfuric acid. It is used in dyeing, manufacturing glass, and in the preparation of sodium bisulfate.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy 3003 resisted solid sodium sulfate under laboratory conditions of 100% relative humidity and ambient temperature. In other tests run at ambient temperature, aqueous solutions of sodium sulfate in concentrations of 0.1 to 14% mildly attacked (0.05 mm/yr, or 2 mils/yr) aluminum alloy 1100. Sodium sulfate has been handled in aluminum alloy tote bins.

P/M Superalloys. Pure sodium sulfate heavily corroded P/M LC Astroloy and isostatically pressed IN-100 samples. The addition of a heat treatment and coarse powder lowered the susceptibility to catastrophic corrosion.

Copper. A sample of C26000 that was polarized at a potential of 0.25 V versus SHE, subjected to constant strain, and immersed in a solution of 1*N* sodium sulfate and 0.01*N* sulfuric acid, was found to suffer stress-corrosion cracking.

Nickel. In hot corrosion tests for automotive applications, a weight loss of 5% was recorded when a sample of Inconel alloy X-750 was exposed for 100 h in a 90% sodium sulfate and 10% sodium chloride air mixture.

Titanium. Although unalloyed titanium was attacked by concentrated sodium sulfate solutions, crevice attack was dependent on the combination of pH and temperature. Grade 2 titanium alloy resisted crevice attack by a simulated acid sulfate galvanizing solution (pH 1.3) at temperatures below 100 °C (212 °F); grades 7 and 12 resisted attack under all conditions. Results indicate that threshold temperatures for crevice corrosion in sulfate solution are much higher than those for chloride solutions.

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Miscellaneous									
High purity lead	L50001	...	...	Saturated	24 (75)	...	.03 (1)	...	254
Lead	L50045	...	...	Saturated	24 (75)	...	0.025 (1)	...	49
Lead	L50045	...	...	2-20	24 (75)	...	0.05 (2) max	...	95
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	1.6 (64)	...	12
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Boiling	...	0.05 (2) max	...	9
Tin	...	...	...	...	20 (68)	...	Resistant	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet	...	5	80 (176)	7 d	Resistant	...	44
Incoloy 800	N08800	Cold-rolled, annealed sheet	...	10	80 (176)	7 d	0.003 (0.1) max	...	44
Inconel 601	N06601	...	...	5	80 (176)	7 d	Resistant	...	64
Inconel 601	N06601	...	...	10	80 (176)	7 d	0.002 (0.1) max	...	64
Inconel 690	N06690	...	...	5	80 (176)	...	0.03 (1) max	...	57
Inconel 690	N06690	...	...	10	80 (176)	...	0.03 (1) max	...	57

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Titanium	...	...	...	10-20	Boiling	...	Resistant	...	90
Titanium, grade 12	R53400	...	Tight crevices pH 2	10	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 2	10	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 2	10	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 2	10	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	pH 1	10	Boiling	...	Resistant	...	33
Titanium, grade 7	R52400	...	Tight crevices pH 2	10	Boiling	...	Resistant	...	215
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Zr702	R60702	...	...	0-20	Room to 100 (212)	...	0.05 (2) max	...	15
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Sodium sulfate saturated slurry, plus 1% zinc sulfate, sodium hydroxide, pH 8.5-9, evaporator	Saturated	110 (230)	193 d	0.003 (0.1)	...	89
304	S30400	...	Paper processing; strong aeration; rapid agitation. Top waters from organic yellow pigment, plus 3% sodium acetate, 1.6% sodium chloride	20-25	70-80 (158-176)	7.5 d	0.02 (0.6)	Slight pitting; crevice attack	89
304	S30400	...	Pharmaceutical procrssing; slight to moderate aeration; rapid agitation. Plus 4% chloride ion, 4% ferric ion, 1% phosphate ion, pH 1-2.5	14.8	52 (125)	20 d	0.07 (2.8)	Severe pitting; crevice attack	89
304	S30400	...	Rayon processing; slight to moderate aeration; rapid agitation. Saturated sodium sulfate solution, 20% crystals	Saturated	76 (170)	48 d	0.003 (0.1)	...	89
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Resistant	...	121
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Sodium sulfate saturated slurry, plus 1% zinc sulfate, sodium hydroxide, pH 8.5-9, evaporator	Saturated	110 (230)	193 d	0.003 (0.1)	...	89

(Continued)

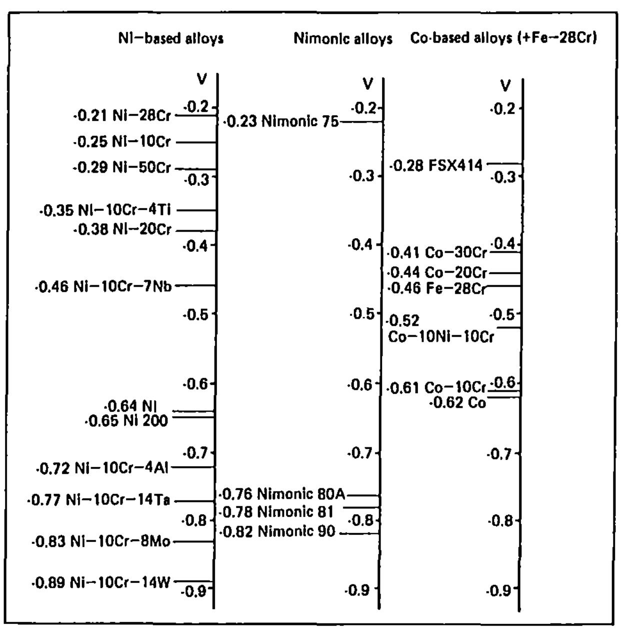
Corrosion Behavior of Various Metals and Alloys in Sodium Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Paper processing; strong aeration; rapid agitation. Top waters from organic yellow pigment, plus 3% sodium acetate, 1.6% sodium chloride	20-25	70-80 (158-176)	7.5 d	0.008 (0.3)	Crevice attack	89
316	S31600	...	Pharmaceutical processing; slight to moderate aeration; rapid agitation. Plus 4% chloride ion, 4% ferric ion, 1% phosphate ion, pH 1-2.5	14.8	52 (125)	20 d	0.03 (1)	Severe pitting; crevice attack	89
316	S31600	...	Rayon processing; slight to moderate aeration; rapid agitation. Saturated sodium sulfate solution, 20% crystals	Saturated	76 (170)	48 d	0.003 (0.1)	...	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317	S31700	...	No aeration; rapid agitation. Sodium sulfate saturated slurry, plus 1% zinc sulfate, sodium hydroxide, pH 8.5-9, evaporator	Saturated	110 (230)	193 d	0.003 (0.1)	...	89
317	S31700	...	Rayon processing; slight to moderate aeration; rapid agitation. Saturated sodium sulfate solution, 20% crystals	Saturated	76 (170)	48 d	0.003 (0.1)	...	89
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Good	...	253
405	S40500	...	...	Saturated	Boiling	...	Good	...	253
409	S40900	...	...	Saturated	Boiling	...	Good	...	253
410	S41000	...	...	10	21 (70)	...	Questionable	...	121
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	Saturated	Boiling	...	Good	...	253
416	S41600	...	...	Saturated	Boiling	...	Good	...	253
420	S42000	...	...	Saturated	Boiling	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	Saturated	20 (68)	...	Resistant	...	253
430	S43000	...	...	Saturated	Boiling	...	Resistant	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253

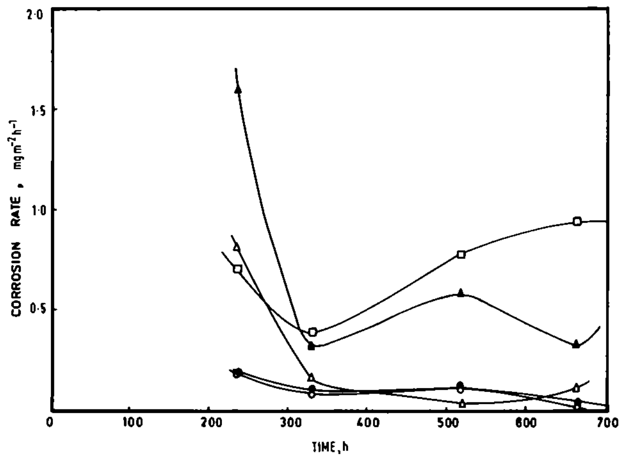
Weight Loss and Corrosion Product Analysis After 120-h Exposure of Aluminum in Sodium Sulfate Solutions

Na_2SO_4 (Molarity)	p (atm)	Al Solution ($\mu g \cdot cm^{-2}$)	Corrosion Product Analysis: Al^{+++} ($\mu g \cdot cm^{-2}$)	Na^{+} ($\mu g \cdot cm^{-2}$)	SO_4^{--} ($\mu g \cdot cm^{-2}$)	X-ray Diffractometry		Al Total Dissolution ($\mu g \cdot cm^{-2}$)
10^{-2}	1	157 ± 10	92 ± 8	8.5 ± 0.3	22 ± 2.0	$Al_{10}O_{15} \cdot H_2O$	(22-1119)	249 ± 12
						$Al(OH)_3$	(7-324)	
	300	210 ± 18	76 ± 7	3.0 ± 0.2	5.7 ± 0.3	$5Al_2O_3 \cdot H_2O$	(15-740)	286 ± 19
5×10^{-2}	1	88 ± 7	71 ± 6	4.1 ± 0.3	5.1 ± 0.4	$\alpha\, Al_2O_3$	(10-173)	159 ± 9
						$Al(OH)_3$	(20-11)	
	300	50 ± 6	80 ± 8	3.0 ± 0.2	6.8 ± 0.4	$\alpha\, Al_2O_3$	(10-173)	130 ± 10
10^{-1}	1	35 ± 4	69 ± 7	3.4 ± 0.2	1.7 ± 0.3	$\alpha\, Al_2O_3$	(10-173)	104 ± 8
						$Al_{10}O_{15} \cdot H_2O$	(22-1119)	
	300	19 ± 3	97 ± 10	1.2 ± 0.1	2.1 ± 0.2	$\alpha\, Al_2O_3$	(10-173)	116 ± 10
Not corroded	—	—	0.5 ± 0.1	—	—			

Source: A.M. Beccaria and G. Poggi, "Aluminum Corrosion in Slightly Alkaline Sodium Sulfate Solutions at Different Hydrocaustic Pressures," *Corrosion*, Vol 43, Mar 1987, 154.



Various alloys. Half-immersion tests: galvanic series in equimolar Na_2SO_4/NaCl melts at 700 °C (against a Pt wire reference electrode). Source: P.D.W. Bottomley, J.L. Dawson, *et al.*, "Semi-immersed Galvanic Series in Na_2SO_4/NaCl Melts and a Comparison with Full-Immersion Potentials," *High Temperature Technology*, Vol 4, Feb 1986, 37-45.



Carbon steel. Variation with time of corrosion rate of carbon steel in 0.76 g/L $Ca(OH)_2$ solutions containing various concentrations of Na_2SO_4. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in Presence of Corrosion Activators," *British Corrosion Journal*, Vol 20, Jan 1985, 34.

LIVE GRAPH
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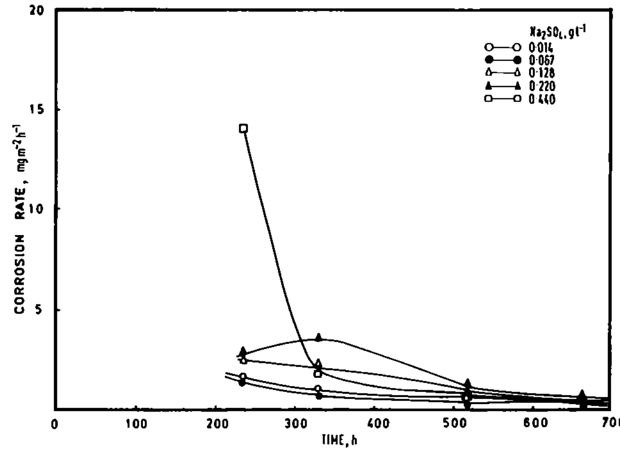

Carbon steel. Variation with time of corrosion rate of carbon steel in 0.43 g/L $Ca(OH)_2$ solutions containing various concentrations of Na_2SO_4. Source: A.P. Akolzin, P. Ghosh, *et al.*, "Application and Peculiarity of $Ca(OH)_2$ as Inhibitor in Presence of Corrosion Activators," *British Corrosion Journal*, Vol 20, Jan 1985, 34.

LIVE GRAPH
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Sodium Sulfide

Sodium sulfide, Na_2S, also known as sodium sulfuret, is an irritating, water-soluble, yellowish to reddish, deliquescent powder that melts at 1180 °C (2156 °F). Sodium sulfide is used as a chemical intermediate and solvent, in conversion of wood into paper pulp, as a photographic and analytical reagent, as a source of sulfide, as a reducing agent, in organic reactions, as a depilatory, and in sheep dips.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Solid sodium sulfide was very corrosive to 3003 and 5154 alloys in laboratory tests conducted under conditions of 100% relative humidity at ambient temperature.

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Ampco 8, aluminum bronze	C61300	...	Generally not suitable	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
High purity lead	L50001	...	...	10	24 (75)	...	.03 (1)	...	254
Lead	L50045	...	...	10	24 (75)	...	0.03 (1)	...	49
Magnesium	...	...	...	3	Room	...	Resistant	...	119
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Platinum	P04995	...	Melt	...	700 (1290)	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Room	...	Good	...	9
Tin	...	...	...	...	20 (68)	...	Poor	...	94
Tin	...	...	...	...	60 (140)	...	Poor	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Nickel and alloys									
Alloy 825	N08825	...	No aeration; slight to moderate agitation. Concentration 40% initially, 45% sodium hydrosulfide final concentration	40	90 (194)	160 d	0.01 (0.5)	...	89
Refractory metals and alloys									
Titanium	...	...	...	10	Boiling	...	0.03 (1.1)	...	90
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Zr702	R60702	...	...	33	Boiling	...	Resistant	...	15
Zr705	R60705	...	...	33	Boiling	...	Resistant	...	15
Stainless steels									
301	S30100	...	Saturated solution	25	Boiling	...	Resistant	...	253
301	S30100	...	Saturated solution	25	100 (212)	...	Good	...	253
302	S30200	...	Saturated solution	25	Boiling	...	Resistant	...	253
302	S30200	...	Saturated solution	25	100 (212)	...	Good	...	253
303	S30300	...	Saturated solution	25	Boiling	...	Questionable	...	253
303	S30300	...	Saturated solution	25	Boiling	...	Resistant	...	253
303	S30300	...	Saturated solution	25	100 (212)	...	Good	...	253
304	S30400	Annealed	...	30	54 (130)	...	0.23 (9.1)	...	19
304	S30400	Annealed	...	40	Boiling	...	0.04 (1.5)	...	19
304	S30400	...	Chemical processing; field or pilot plant test; no aeration; rapid agitation. Evaporator, vapors	30	124 (255)	30 d	0.19 (7.5)	...	89
304	S30400	...	No aeration; no agitation	60	171 (340)	28 d	.09 (36)	...	89
304	S30400	...	No aeration; rapid agitation. Evaporator	10	85 (185)	21 d	0.013 (0.5)	...	89
304	S30400	...	No aeration; rapid agitation. Evaporator, vapors	15	85 (185)	30 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; rapid agitation. With carbon over the standard maximum. Evaporator	10	85 (185)	21 d	0.003 (0.1)	...	89

(Continued)

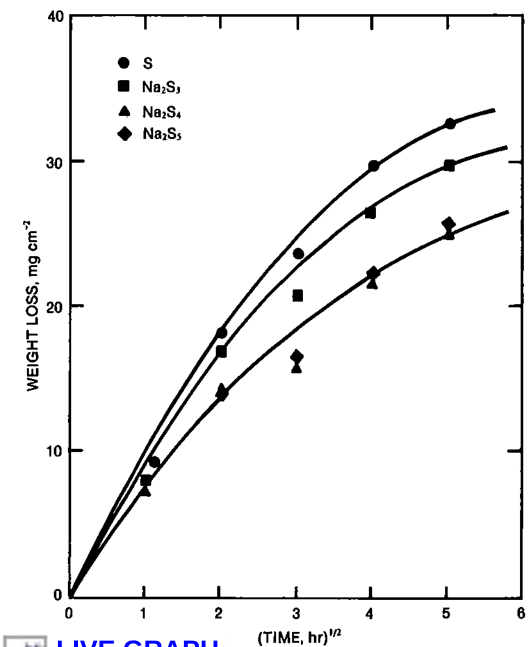
Corrosion Behavior of Various Metals and Alloys in Sodium Sulfide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	No aeration; rapid agitation. With carbon over the standard maximum. Evaporator, vapors	15	85 (185)	30 d	0.003 (0.1)	...	89
304	S30400	...	No aeration; slight to moderate agitation. Concentration 40% initially, 45% sodium hydrosulfide final concentration	40	90 (194)	160 d	0.07 (2.6)	...	89
304	S30400	...	Saturated solution	25	Boiling	...	Resistant	...	253
304	S30400	...	Saturated solution	25	100 (212)	...	Good	...	253
304L	S30403	...	Saturated solution	25	Boiling	...	Resistant	...	253
304L	S30403	...	Saturated solution	25	100 (212)	...	Good	...	253
304LN	S30453	...	Saturated solution	25	Boiling	...	Resistant	...	253
304LN	S30453	...	Saturated solution	25	100 (212)	...	Good	...	253
316	S31600	Annealed	...	30	54 (130)	...	0.53 (21)	...	19
316	S31600	Annealed	...	40	Boiling	...	0.06 (2.5)	...	19
316	S31600	...	No aeration; no agitation	60	171 (340)	28 d	1.0 (38)	...	89
316	S31600	...	No aeration; rapid agitation. Evaporator	10	85 (185)	21 d	.003 (0.1)	...	89
316	S31600	...	No aeration; slight to moderate agitation. Concentration 40% initially, 45% sodium hydrosulfide final concentration	40	90 (194)	160 d	0.9 (3.9)	...	89
316	S31600	...	Saturated solution	25	Boiling	...	Resistant	...	253
316	S31600	...	Saturated solution	25	100 (212)	...	Good	...	253
316F	S31620	...	Saturated solution	25	Boiling	...	Resistant	...	253
316F	S31620	...	Saturated solution	25	100 (212)	...	Good	...	253
316L	S31603	...	Saturated solution	25	Boiling	...	Resistant	...	253
316L	S31603	...	Saturated solution	25	100 (212)	...	Good	...	253
316LN	S31653	...	Saturated solution	25	Boiling	...	Resistant	...	253
316LN	S31653	...	Saturated solution	25	100 (212)	...	Good	...	253
316Ti	S31635	...	Saturated solution	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	Saturated solution	25	100 (212)	...	Good	...	253
317	S31700	...	No aeration; rapid agitation. Evaporator, vapors	15	85 (185)	30 d	0.003 (0.1)	...	89
317	S31700	...	No aeration; rapid agitation. Evaporator, vapors	30	124 (255)	30 d	0.5 (19)	...	89
317L	S31703	...	Saturated solution	25	Boiling	...	Resistant	...	253
317L	S31703	...	Saturated solution	25	100 (212)	...	Good	...	253
317LN	S31725	...	Saturated solution	25	Boiling	...	Resistant	...	253
317LN	S31725	...	Saturated solution	25	100 (212)	...	Good	...	253
321	S32100	...	Saturated solution	25	Boiling	...	Resistant	...	253
321	S32100	...	Saturated solution	25	100 (212)	...	Good	...	253
329	S32900	...	Saturated solution	25	Boiling	...	Resistant	...	253
329	S32900	...	Saturated solution	25	100 (212)	...	Good	...	253
347	S34700	...	Saturated solution	25	Boiling	...	Resistant	...	253
347	S34700	...	Saturated solution	25	100 (212)	...	Good	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
430	S43000	...	Saturated solution	25	Boiling	...	Questionable	...	253
434	S43400	...	Saturated solution	25	Boiling	...	Good	...	253
Carpenter 20	...	...	No aeration; no agitation; cast specimens	60	171 (340)	28 d	2.0 (81)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carpenter 20	...	...	No aeration; slight to moderate agitation. Concentration 40% initially, 45% sodium hydrosulfide final concentration	40	90 (194)	160 d	0.04 (1.5)	...	89
F51	S31803	...	Saturated solution	25	Boiling	...	Resistant	...	253
F51	S31803	...	Saturated solution	25	100 (212)	...	Good	...	253



LIVE GRAPH
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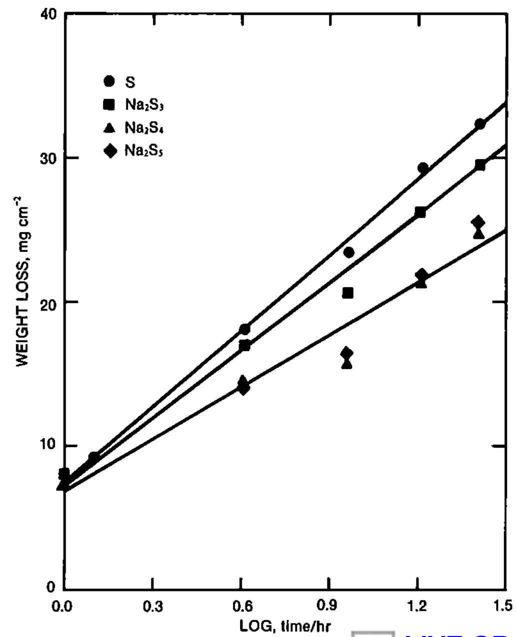
Nickel. Corrosion behavior of nickel plotted as weight loss due to corrosion vs. the square root of the time of corrosion at 350 °C. Source: A.P. Brown and J.E. Battles, Corrosion of Nickel-200 and AISI-1008 Steel in Sodium Polysulfides and Sulfur at 350 °C, *Journal of the Electrochemical Society*, Vol 133, July 1986, 1322.



LIVE GRAPH
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Nickel. Corrosion behavior of nickel plotted as weight loss vs. the logarithm of time at 350 °C. Source: A.P. Brown and J.E. Battles, Corrosion of Nickel-200 and AISI-1008 Steel in Sodium Polysulfides and Sulfur at 350 °C, *Journal of the Electrochemical Society*, Vol 133, July 1986, 1323.

Sodium Sulfite

Sodium sulfite, Na_2SO_3, is a white, water-soluble, crystalline solid with a sulfurous, salty taste. It decomposes when heated. Sodium sulfite is used as a source of sulfite, as a chemical intermediate and food preservative, in medicine and paper manufacturing, in photographic developing, and as a bleaching agent in the textile industry. Most boiler operators use sodium sulfite for chemical scavenging of oxygen in the feedwater. Because it decomposes into acidic gases at the high temperatures that accompany high pressures, sodium sulfite should not be used for this purpose at pressures above 122 atm (12.4 MPa, or 1.8 ksi).

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for cor-

rosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In laboratory tests conducted at 100% relative humidity and ambient temperature, aluminum alloys 3003 and 5154 resisted solid sodium sulfite. Alloy 1100 resisted aqueous solutions (0.1 to 15%) of sodium sulfite in tests run at ambient temperature.

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfite

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Magnesium alloy AZ61A	M11610	...	Specimens were alternately immersed 30 s in solution and held 2 min in air	3	35 (95)	7 d	0.005 (1.6)	...	12
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Refractory metals and alloys									
Titanium	...	...	...	Saturated	Boiling	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Questionable	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	Pulp and paper processing; no aeration; no agitation. Plus sodium bicarbonate, pH 7.5	~6.84	24 (75)	28 d	0.003 (0.1) max	...	89
304	S30400	...	Tanning; rapid agitation; with carbon over the standard maximum. Plus organic acids, sulfurous acid, tannins (under false bottom of quebracho bisulfiting tank)	3	...	180 d	0.003 (0.1)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Sulfite (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	Pulp and paper processing; test; no aeration; no agitation. Plus sodium bicarbonate, pH 7.5	~6.84	24 (75)	28 d	0.003 (0.1) max	...	89
316	S31600	...	Tanning; rapid agitation. Plus organic acids, sulfurous acid, tannins (under false bottom of quebracho bisulfiting tank)	3	...	180 d	0.003 (0.1)	...	89
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
403	S40300	...	...	50	Boiling	...	Questionable	...	253
405	S40500	...	...	50	Boiling	...	Questionable	...	253
409	S40900	...	...	50	Boiling	...	Questionable	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	Saturated	Room	...	Resistant	...	121
410	S41000	...	...	50	Boiling	...	Questionable	...	253
416	S41600	...	...	50	Boiling	...	Questionable	...	253
420	S42000	...	...	50	Boiling	...	Questionable	...	253
430	S43000	...	...	50	Boiling	...	Questionable	...	253
434	S43400	...	...	50	Boiling	...	Good	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
F51	S31803	...	...	50	Boiling	...	Resistant	...	253

Sodium Thiosulfate

Sodium thiosulfate, $Na_2S_2O_3 \cdot 5H_2O$, also known as sodium hyposulfite, hypo, and sodium subsulfite, is a white crystalline solid that has a melting point of 48 °C (118 °F). Water soluble, it is used as a fixing agent for photographic films, plates, and papers. Sodium thiosulfate is used in medicine, as a germicide, in manufacturing leather, as a mordant in dyeing, and for extracting silver from ore.

Corrosion Behavior of Various Metals and Alloys in Sodium Thiosulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Solution	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93

(Continued)

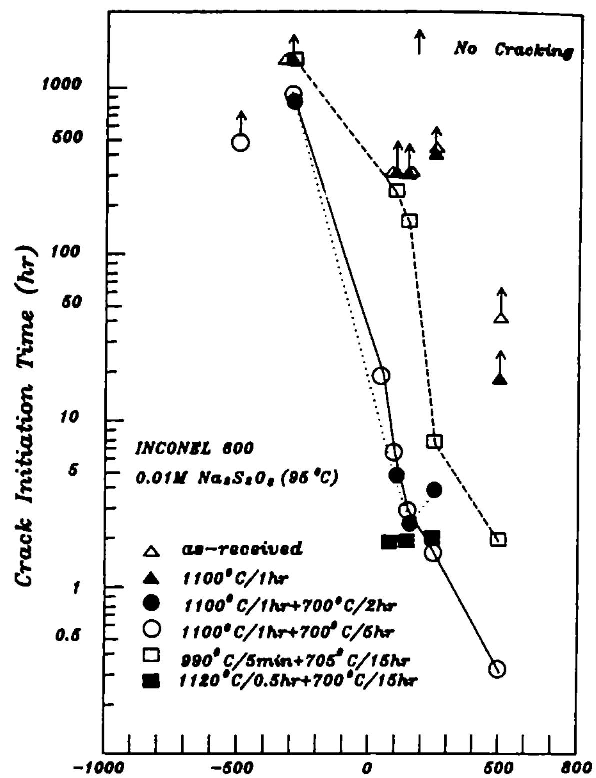
Corrosion Behavior of Various Metals and Alloys in Sodium Thiosulfate (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Questionable	...	93
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Questionable	...	93
Electrolytic copper	C11000	...	...	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel- silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Questionable	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Questionable	...	93
Phosphor copper	C12200	...	...	...	...	...	Questionable	...	93
Red brass	C23000	...	...	...	...	...	Questionable	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Questionable	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Questionable	...	93
Miscellaneous									
Platinum	P04995	...	...	All	Boiling	...	0.05 (2) max	...	5
Silver	P07010	...	...	All	Room	...	0.05 (2) max	...	9
Refractory metals and alloys									
Titanium	...	...	...	25	Boiling	...	Resistant	...	90
Titanium	...	...	Plus 20% CH_3OCOOH	20	Room	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	25	20 (68)	...	Resistant	...	253
301	S30100	...	...	25	Boiling	...	Resistant	...	253
302	S30200	...	...	25	20 (68)	...	Resistant	...	253
302	S30200	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	20 (68)	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
303	S30300	...	...	25	Boiling	...	Resistant	...	253
304	S30400	...	...	25	20 (68)	...	Resistant	...	253
304	S30400	...	...	25	Boiling	...	Resistant	...	253
304L	S30403	...	...	25	20 (68)	...	Resistant	...	253
304L	S30403	...	...	25	Boiling	...	Resistant	...	253
304LN	S30453	...	...	25	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	25	Boiling	...	Resistant	...	253
316	S31600	...	...	25	20 (68)	...	Resistant	...	253
316	S31600	...	...	25	Boiling	...	Resistant	...	253
316F	S31620	...	...	25	20 (68)	...	Resistant	...	253
316F	S31620	...	...	25	Boiling	...	Resistant	...	253
316L	S31603	...	...	25	20 (68)	...	Resistant	...	253
316L	S31603	...	...	25	Boiling	...	Resistant	...	253
316LN	S31653	...	...	25	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	25	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	25	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	25	Boiling	...	Resistant	...	253
317L	S31703	...	...	25	20 (68)	...	Resistant	...	253
317L	S31703	...	...	25	Boiling	...	Resistant	...	253
317LN	S31725	...	...	25	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	25	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sodium Thiosulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	...	25	20 (68)	...	Resistant	...	253
321	S32100	...	...	25	Boiling	...	Resistant	...	253
329	S32900	...	...	25	20 (68)	...	Resistant	...	253
329	S32900	...	...	25	Boiling	...	Resistant	...	253
347	S34700	...	...	25	20 (68)	...	Resistant	...	253
347	S34700	...	...	25	Boiling	...	Resistant	...	253
430	S43000	...	...	25	20 (68)	...	Resistant	...	253
430	S43000	...	...	25	Boiling	...	Resistant	...	253
434	S43400	...	...	25	20 (68)	...	Resistant	...	253
434	S43400	...	...	25	Boiling	...	Resistant	...	253
F51	S31803	...	...	25	20 (68)	...	Resistant	...	253



LIVE GRAPH
Click here to view

Inconel 600. The variation of crack initiation time with applied potential for Alloy 600 with different heat treatments in 0.01 M thiosulfate solution at 95 °C (203 °F). Ref. 193

Soils

Soils are defined as unconsolidated rock material over bedrock and/or freely divided rock-derived material containing an admixture of organic matter and capable of supporting vegetation.

Worldwide, corrosion of metals in soil is responsible for a large percentage of corrosion and corrosion failures. While several individual characteristics of soils have been used to indicate the corrosivity of soils, no

method currently describes the synergistic effects of these characteristics. In particular, the corrosivity of soil is based largely upon the interaction of resistivity, dissolved salts, moisture content, pH, bacterial activity, and concentration of oxygen. Other secondary factors are also important but are more difficult to define. Thus, simply testing metals in a variable pH solution or in aerated or deaerated solutions will not accurately describe the conditions in soil. Often field testing must be performed to determine the corrosion rate and the program methods for corrosion control.

Corrosion Behavior of Various Metals and Alloys in Soils

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
Cast steel	...	...	Bentonite backfill, 10 cm depth	...	...	2.3 yr	.003 (0.12)	...	201
Cast steel	...	...	Granite backfill, 10 cm depth	...	...	2.5 yr	.026 (1.0)	...	201
Steel	G10100	Forged	Bentonite backfill, 10 cm depth	...	...	2.3 yr	.007 (0.28)	...	201
Steel	G10100	Forged	Granite backfill, 10 cm depth	...	...	2.5 yr	.025 (1.0)	...	201
Copper and alloys									
OFE Copper	C10100	...	Bentonite and silica sand with saline water (34,000 ppm chloride)	...	50-100	2 yr	.02 (0.8)	...	188

Stannic Chloride

Also known as tin chloride, tin tetrachloride, and tin perchloride, $SnCl_4$ is a colorless, fuming liquid, soluble in cold water, alcohol, carbon disulfide, and oil of turpentine, that is decomposed by hot water, and boils at 114 °C. Used as a conductive coating and a sugar bleach, and in drugs, ceramics, soaps, and blueprinting.

Corrosion Behavior of Various Metals and Alloys in Stannic Chloride

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Poor	Pitting	253
301	S30100	...	...	...	Boiling	...	Poor	Pitting	253
302	S30200	...	...	...	20 (68)	...	Poor	Pitting	253
302	S30200	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Poor	Pitting	253
304	S30400	...	...	...	Boiling	...	Poor	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Poor	Pitting	253
304L	S30403	...	...	...	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Poor	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Poor	Pitting	253
316	S31600	...	...	...	20 (68)	...	Questionable	Pitting	253
316	S31600	...	...	...	Boiling	...	Poor	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Poor	Pitting	253
316F	S31620	...	...	...	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Questionable	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Stannic Chloride (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	...	Boiling	...	Poor	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Questionable	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Poor	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Questionable	Pitting	253
316Ti	S31635	...	...	...	Boiling	...	Poor	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Questionable	Pitting	253
317L	S31703	...	...	...	Boiling	...	Poor	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Questionable	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Poor	Pitting	253
321	S32100	...	...	...	20 (68)	...	Poor	Pitting	253
321	S32100	...	...	...	Boiling	...	Poor	Pitting	253
329	S32900	...	...	...	20 (68)	...	Questionable	Pitting	253
329	S32900	...	...	...	Boiling	...	Poor	Pitting	253
347	S34700	...	...	...	20 (68)	...	Poor	Pitting	253
347	S34700	...	...	...	Boiling	...	Poor	Pitting	253
403	S40300	...	...	...	20 (68)	...	Poor	Pitting	253
403	S40300	...	...	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Poor	Pitting	253
405	S40500	...	...	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Poor	Pitting	253
409	S40900	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Poor	Pitting	253
410	S41000	...	...	...	Boiling	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Poor	Pitting	253
416	S41600	...	...	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Poor	Pitting	253
420	S42000	...	...	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Poor	Pitting	253
430	S43000	...	...	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	...	20 (68)	...	Poor	Pitting	253
434	S43400	...	...	...	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Questionable	Pitting	253
F51	S31803	...	...	...	Boiling	...	Poor	Pitting	253

Stannous Chloride

Also known as tin chloride, tin crystals, tin dichloride and tin salts, $SnCl_2$ is white crystals, soluble in water, alcohol, and alkalies, oxidized in air to the oxychloride, that melt at 247 °C. Used as a chemical intermediate, reducing agent, and ink-stain remover, and for silvering mirrors.

Corrosion Behavior of Various Metals and Alloys in Stannous Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	50 (122)	...	Good	Pitting	253
301	S30100	...	...	Saturated	Boiling	...	Poor	Pitting	253

(Continued)

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Corrosion Behavior of Various Metals and Alloys in Stannous Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	Saturated	50 (122)	...	Good	Pitting	253
302	S30200	...	...	Saturated	Boiling	...	Poor	Pitting	253
303	S30300	...	...	Saturated	50 (122)	...	Questionable	Pitting	253
303	S30300	...	...	Saturated	50 (122)	...	Good	Pitting	253
303	S30300	...	...	Saturated	Boiling	...	Poor	Pitting	253
303	S30300	...	...	Saturated	Boiling	...	Poor	Pitting	253
304	S30400	...	...	Saturated	50 (122)	...	Good	Pitting	253
304	S30400	...	...	Saturated	Boiling	...	Poor	Pitting	253
304L	S30403	...	...	Saturated	50 (122)	...	Good	Pitting	253
304L	S30403	...	...	Saturated	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	Saturated	50 (122)	...	Good	Pitting	253
304LN	S30453	...	...	Saturated	Boiling	...	Poor	Pitting	253
316	S31600	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
316	S31600	...	...	Saturated	Boiling	...	Poor	Pitting	253
316F	S31620	...	...	Saturated	50 (122)	...	Good	Pitting	253
316F	S31620	...	...	Saturated	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
316L	S31603	...	...	Saturated	Boiling	...	Poor	Pitting	253
316LN	S31653	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
316LN	S31653	...	...	Saturated	Boiling	...	Poor	Pitting	253
316Ti	S31635	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
316Ti	S31635	...	...	Saturated	Boiling	...	Poor	Pitting	253
317L	S31703	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
317L	S31703	...	...	Saturated	Boiling	...	Poor	Pitting	253
317LN	S31725	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
317LN	S31725	...	...	Saturated	Boiling	...	Poor	Pitting	253
321	S32100	...	...	Saturated	50 (122)	...	Good	Pitting	253
321	S32100	...	...	Saturated	Boiling	...	Poor	Pitting	253
329	S32900	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
329	S32900	...	...	Saturated	Boiling	...	Poor	Pitting	253
347	S34700	...	...	Saturated	50 (122)	...	Good	Pitting	253
347	S34700	...	...	Saturated	Boiling	...	Poor	Pitting	253
403	S40300	...	...	Saturated	50 (122)	...	Poor	Pitting	253
403	S40300	...	...	Saturated	Boiling	...	Poor	Pitting	253
405	S40500	...	...	Saturated	50 (122)	...	Poor	Pitting	253
405	S40500	...	...	Saturated	Boiling	...	Poor	Pitting	253
409	S40900	...	...	Saturated	50 (122)	...	Poor	Pitting	253
409	S40900	...	...	Saturated	Boiling	...	Poor	Pitting	253
410	S41000	...	...	Saturated	50 (122)	...	Poor	Pitting	253
410	S41000	...	...	Saturated	Boiling	...	Poor	Pitting	253
416	S41600	...	...	Saturated	50 (122)	...	Poor	Pitting	253
416	S41600	...	...	Saturated	Boiling	...	Poor	Pitting	253
420	S42000	...	...	Saturated	50 (122)	...	Poor	Pitting	253
420	S42000	...	...	Saturated	Boiling	...	Poor	Pitting	253
430	S43000	...	...	Saturated	50 (122)	...	Questionable	Pitting	253
430	S43000	...	...	Saturated	Boiling	...	Poor	Pitting	253
434	S43400	...	...	Saturated	50 (122)	...	Questionable	Pitting	253
434	S43400	...	...	Saturated	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	Saturated	50 (122)	...	Resistant	Pitting	253
F51	S31803	...	...	Saturated	Boiling	...	Poor	Pitting	253

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Steam

The corrosive properties of the steam that will be used in a plant are seldom considered, particularly if the steam will be supplied by a public utility or power plant in which boiler water treatment is sufficient to prevent condensate corrosion. However, the impurities in steam can cause corrosion problems.

At one site, for example, high-pressure steam was purchased from a central power station, and there were no problems for 15 years. Within a few months after routine work, however, cracks and resulting leaks appeared adjacent to and across the welded joints in the new piping. Metallographic examination showed that the cracking was the result of caustic embrittlement. The deionized water contained 10 ppm sodium, which formed concentrated sodium hydroxide (NaOH) as the water evaporated. The older piping did not crack, because it had been stress relieved by the superheated steam over a period of years before cooling of the steam was initiated.

In the majority of cases, it is not necessary to treat steam condensate before it is reused, and boiler feedwater is prepared simply by adding makeup water to the condensate. However, condensate is sometimes contaminated by the corrosion products or by the leaking in of cooling water or other undesirable substances. In such cases, the corrosion must be reduced, or the unwanted contaminants removed, before the condensate can be recycled. When steam contains acidic gases such as carbon dioxide and oxygen, its condensate will be acidic and as a result will cause corrosion of metal surfaces.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Copper. Copper and copper alloys resist attack by pure steam, but if much carbon dioxide, oxygen, or ammonia is present, the condensate is corrosive. Even though wet steam at high velocities can cause severe impingement attack, copper alloys are used extensively in condensers and heat exchangers. Copper alloys are also used for feedwater heaters, although their use in such applications is somewhat limited because of their rapid decline in strength and creep resistance at moderately elevated temperatures. Copper nickels are the preferred copper alloys for the higher temperatures and pressures.

Use of copper in systems handling hot water and steam is limited by the working pressures of tubes and joints. A few copper alloys have shown a tendency to fail by stress-corrosion cracking when they are highly stressed and exposed to steam. Alpha aluminum bronzes that do not contain tin are among the alloys susceptible to this type of failure. Copper-silicon alloys, which generally have the same corrosion resistance as copper, appear to be much more resistant to stress-corrosion cracking than the common brasses. Silicon bronzes are susceptible to embrittlement by high-pressure steam and should be tested for suitability in the service environment before being specified for components to be used at elevated temperature.

Steam condensate that has been properly treated so that it is relatively free of gases, as in a power-generating station, is relatively noncorrosive to copper and copper alloys. Rates of attack in such exposures are less than 2.5 μm/yr (0.1 mil/yr). Copper and its alloys are not attacked by condensate that contains a significant amount of oil, such as condensate from a reciprocating steam engine.

Dissolved carbon dioxide, oxygen, or both significantly increase the rate of attack. For example, condensate with 4.6 ppm oxygen, and 14 ppm carbon dioxide, and a pH of 5.5 at 68 °C (155 °F) caused an average penetration of 175 to 350 μm/yr (6.9 to 13.8 mils/yr) when in contact with C12200 (phosphorus-deoxidized copper), C14200 (arsenical copper), C23000 (red brass), C44300 to C44500 (admiralty metal), and C71000 (copper nickel, 20%). Steel tested under the same conditions was penetrated at about twice the rate given for the copper alloys listed above, but tin-coated copper proved to be much more resistant and was attacked at a rate of less than 25 μm/yr (1 mil/yr). To attain the optimum service life in condensate systems, it is necessary to ensure that the tubes are installed with enough slope to allow proper drainage, to reduce the quantity of corrosive gases (usually carbon dioxide and oxygen) at the source by mechanical or chemical treatment of the feedwater, or to treat the steam chemically.

Modern power utility boiler feedwater treatments commonly include the addition of organic amines and oxygen scavengers to inhibit the corrosion of iron components in the system by scavenging oxygen and increasing the pH of the feedwater. Chemicals, such as morpholine and hydrazine, decompose in service to yield ammonia, which can be quite corrosive toward some copper alloys. In the main body of well-monitored operating condensers, oxygen and ammonia levels are quite low, and corrosion is usually mild. More aggressive conditions exist in the air removal section. Abnormal operating conditions, tube leakage, and shutdown-startup cycles may also increase the corrosivity of the steam-side environment by raising the oxygen concentration. Laboratory corrosion tests were performed on a number of copper alloys and on low-carbon steel in both aerated (8 to 12 ppm oxygen) and deaerated (100 to 200 ppb oxygen) ammonia solutions. In these tests, ammonia enhanced the corrosion resistance of the copper-nickel alloys, modifying surface oxides by increasing nickel content. Elevated oxygen levels are generally more deleterious than elevated ammonia levels. However, C71500 was minimally affected by the elevated oxygen content.

Nickel. The nickel-chromium-iron alloys are very popular materials for critical applications in pressurized and boiling water reactors, because of their excellent corrosion resistance in steam and water environments and because of their resistance to chloride stress-corrosion cracking. The age-hardenable alloy Inconel X-750 is used as a spring material for fuel pellet hold-down springs, fuel element divide plates, and reactor scram springs, and for bolting. Another age-hardenable alloy, Inconel 718, because of its high strength and spring characteristics, is also used for fuel assembly divider plates. It also demonstrated excellent wear resistance in sodium fast breeder reactor environments.

In steam-hot water systems such as condensers, appreciable corrosion of Nickel 200 and Monel 400 may occur if noncondensables (carbon dioxide and air) in the steam exist in certain proportions. Deaeration of the feedwater or venting of the noncondensable gases will prevent this attack.

The single most significant application of nickel-base alloys in the nuclear industry has been the use of Inconel 600 for steam generator tubing in pressurized water reactors. Inconel 600 is resistant to all mixtures of steam, air, and carbon dioxide and thus is particularly useful in contact with steam at high temperatures. An alternative material for this application is Inconel 690.

Silver. Silver is resistant to corrosion attack by steam at temperatures up to 600 °C (1110 °F).

Tantalum. No failures caused by exposure of tantalum to steam condensate have ever been recorded. Tantalum is used in many cases at saturated steam pressures above 1035 kPa (150 psi) at temperatures of 185 °C (365 °F) and is considered resistant to saturated steam below 250 °C (480 °F) at a pressure of 3.9 MPa (560 psi). In addition, although few published data have been found on the attack of steam on tantalum at high temperatures, it is known from industrial practice that tantalum is not affected adversely when heated with steam at pressures to 1380 kPa (200 psig), corresponding to a temperature of 200 °C (390 °F). It has been reported that at temperatures above 1125 °C (2240 °F) water is decomposed by tantalum, with adsorption of oxygen by the metal and evolution of hydrogen. At 925 °C (1700 °F) and lower temperatures, the reaction is negligibly slow.

Titanium. Extensive erosion-corrosion testing of titanium alloys Ti-6Al-4V, Ti-5Al-2.5Sn, and Ti-7Al-4Mo has been conducted in high-velocity wet steam environments for application in low-pressure steam turbine blading in power plants. These alloys have demonstrated superior resistance to type 403 stainless steel (12 to 13% Cr steel) in operating turbines and in water droplet erosion and water jet impingement tests. Full erosion resistance of Ti-6Al-4V blades to velocities of 440 to 530 m/s (1450 to 1740 ft/s) at 10% steam moisture has been noted in turbines. In fact, these studies suggest useful erosion resistance of Ti-6Al-4V in approximately 8% steam moisture up to 549 m/s (1800 ft/s) and in 11% steam moisture up to 499 m/s (1600 ft/s). Single-shot water jet impingement testing has shown that annealed Ti-7Al-4Mo alloy is significantly more erosion resistant than 12% Cr steel, type 303 stainless steel, or Stellite alloy 6 at jet velocities of 610 and 915 m/s (2000 and 3000 ft/s).

Zirconium. Corrosion and oxidation of unalloyed zirconium in water and steam are reported to be irregular. This behavior is probably caused by variations in the impurity content in the metal. Nitrogen and carbon impurities are particularly harmful. The corrosion rate of zirconium increases markedly when nitrogen and carbon concentrations exceed 40 and 300 ppm, respectively.

The irregular corrosion behavior of unalloyed zirconium can be seen in the curves for corrosion at 315 and 360 °C (600 and 680 °F). The data for corrosion resistance at 315 °C (600 °F) must be plotted as a band because there is too much scatter in the data. The curve at 360 °C (680 °F) has three bands extending upward from it; each band represents a change in corrosion rate from the basic rate indicated by the single line and represents data from a different set of test specimens.

Zircaloy-2, Zircaloy-4, Zr-2.5Nb, and Zr-1Nb are the most important alloys used in water-cooled nuclear reactors, because they have the most reliable corrosion resistance in high-temperature water and steam. Zircaloy-2 is superior to unalloyed zirconium in high-temperature water and steam.

Zircaloy-4 differs in composition from Zircaloy-2 only in having no nickel and slightly greater iron content. Both variations are intended to reduce hydrogen pickup in reactor operation. The corrosion behavior of Zircaloy-4 is very similar to that of Zircaloy-2. However, hydrogen pickup for Zircaloy-4 is significantly lower, particularly when the alloy is exposed to water at 360 °C (680 °F). At this temperature, hydrogen pickup for Zircaloy-4 is about 25% of theoretical, or less than half that for Zircaloy-2. In addition, hydrogen pickup for Zircaloy-4 is less sensitive to hydrogen overpressure than that for Zircaloy-2. For both Zircaloys, hydrogen pickup is markedly decreased when dissolved oxygen is present in the corrosion medium.

Alloy Zr-2.5Nb is considered to be somewhat less resistant to corrosion than the Zircaloys. Nevertheless, Zr-2.5Nb is acceptable for many applications. An example is the use of Zr-2.5Nb pressure tubes in the primary loops of some reactors. The corrosion resistance of Zr-2.5Nb can be substantially improved by heat treatment. Also, Zr-2.5Nb is superior to Zircaloys in steam at temperatures above 400 °C (750 °F).

Hafnium. The resistance of hafnium to corrosion by steam is superior to that of zirconium and Zircaloy alloys.

Corrosion Behavior of Various Metals and Alloys in Steam

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Carbon and alloy steels									
5Cr-Mo steel	J42045	Cast	0.22% carbon, 5.07% chromium, 0.47% molybdenum	...	650 (1200)	570 h	0.1 (4)	...	107
5Cr-Mo steel	J42045	Cast	0.27% carbon, 5.49% chromium, 0.43% molybdenum	...	650 (1200)	570 h	0.1 (4)	...	107
7Cr-Mo steel	S50300	...	0.11% carbon, 7.33% chromium, 0.59% molybdenum	...	650 (1200)	570 h	0.05 (2)	...	107
9Cr-1.5Mo steel	J82090	Cast	0.23% carbon, 9.09% chromium, 1.56% molybdenum	...	650 (1200)	570 h	0.025 (1)	...	107
C-Mo steel	J12520	Cast	0.20% carbon, 0.49% molybdenum	...	650 (1200)	570 h	0.25 (10)	...	107
C-Mo steel	J12520	Cast	0.21% carbon, 0.49% molybdenum	...	650 (1200)	570 h	0.3 (12)	...	107
Cast steel	J02500	Cast	0.24% carbon	...	650 (1200)	570 h	0.3 (12)	...	107
Cast steel	J02500	Cast	0.25% carbon	...	650 (1200)	570 h	0.28 (11)	...	107
Ni-Cr-Mo	J02500	Cast	0.28% carbon, 0.73% chromium, 2.25% nickel, 0.26% molybdenum	...	650 (1200)	570 h	0.25 (10)	...	107

(Continued)

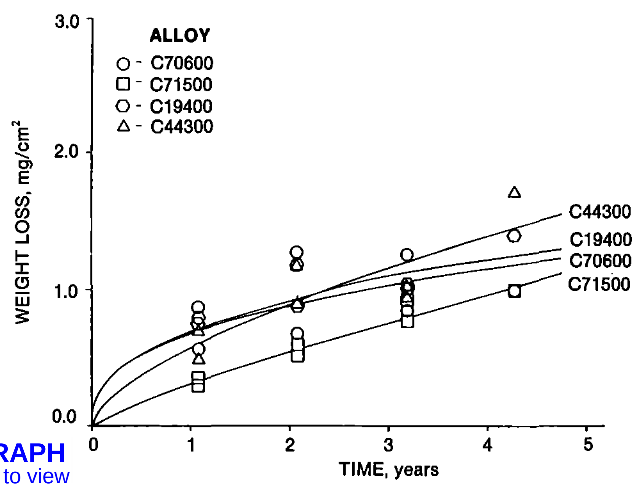
Corrosion Behavior of Various Metals and Alloys in Steam (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Ni-Cr-Mo	J02500	Cast	0.35% carbon, 0.64% chromium, 2.13% nickel, 0.26% molybdenum	...	650 (1200)	570 h	0.25 (10)	...	107
Miscellaneous									
Chemical lead	L51120	...	Condensed with traces of acid. No aeration, slow agitation	...	21-38 (70-100)	...	0.021 (0.85)	...	13
Gold	P00016	...	...	...	800 (1470)	...	0.05 (2) max	...	8
Magnesium	...	...	...	100	...	...	Poor	...	119
Platinum	P04995	...	...	...	600 (1110)	...	0.05 (2) max	...	6
Silver	P07010	...	Without pressure	Pure	600 (1110)	...	0.05 (2) max	...	8
Refractory metals and alloys									
Titanium	...	...	Plus 7.65% H_2S	...	93-100 (200-230)	...	Resistant	...	90
Titanium	...	...	Plus air	...	82 (197)	...	Resistant	...	90
Stainless steels									
301	S30100	...	...	...	400 (752)	...	Resistant	...	253
301	S30100	...	With CO_2	...	...	...	Resistant	...	253
301	S30100	...	With SO_2	...	...	...	Good	...	253
302	S30200	...	...	...	400 (752)	...	Resistant	...	253
302	S30200	...	With CO_2	...	...	...	Resistant	...	253
302	S30200	...	With SO_2	...	...	...	Good	...	253
303	S30300	...	...	...	400 (752)	...	Resistant	...	253
303	S30300	...	...	...	400 (752)	...	Resistant	...	253
303	S30300	...	With CO_2	...	...	...	Questionable	...	253
303	S30300	...	With CO_2	...	...	...	Resistant	...	253
303	S30300	...	With SO_2	...	...	...	Good	...	253
304	S30400	...	...	...	400 (752)	...	Resistant	...	253
304	S30400	...	With CO_2	...	...	...	Resistant	...	253
304	S30400	...	With SO_2	...	...	...	Good	...	253
304L	S30403	...	...	...	400 (752)	...	Resistant	...	253
304L	S30403	...	With CO_2	...	...	...	Resistant	...	253
304L	S30403	...	With SO_2	...	...	...	Good	...	253
304LN	S30453	...	...	...	400 (752)	...	Resistant	...	253
304LN	S30453	...	With CO_2	...	...	...	Resistant	...	253
304LN	S30453	...	With SO_2	...	...	...	Good	...	253
316	S31600	...	...	...	400 (752)	...	Resistant	...	253
316	S31600	...	With CO_2	...	...	...	Resistant	...	253
316	S31600	...	With SO_2	...	...	...	Resistant	...	253
316F	S31620	...	...	...	400 (752)	...	Resistant	...	253
316F	S31620	...	With CO_2	...	...	...	Resistant	...	253
316F	S31620	...	With SO_2	...	...	...	Good	...	253
316L	S31603	...	...	...	400 (752)	...	Resistant	...	253
316L	S31603	...	With CO_2	...	...	...	Resistant	...	253
316L	S31603	...	With SO_2	...	...	...	Resistant	...	253
316LN	S31653	...	...	...	400 (752)	...	Resistant	...	253
316LN	S31653	...	With CO_2	...	...	...	Resistant	...	253
316LN	S31653	...	With SO_2	...	...	...	Resistant	...	253
316Ti	S31635	...	...	...	400 (752)	...	Resistant	...	253
316Ti	S31635	...	With CO_2	...	...	...	Resistant	...	253
316Ti	S31635	...	With SO_2	...	...	...	Resistant	...	253
317L	S31703	...	...	...	400 (752)	...	Resistant	...	253
317L	S31703	...	With CO_2	...	...	...	Resistant	...	253
317L	S31703	...	With SO_2	...	...	...	Resistant	...	253
317LN	S31725	...	...	...	400 (752)	...	Resistant	...	253
317LN	S31725	...	With CO_2	...	...	...	Resistant	...	253
317LN	S31725	...	With SO_2	...	...	...	Resistant	...	253
321	S32100	...	...	...	400 (752)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Steam (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	With CO_2	...	...	...	Resistant	...	253
321	S32100	...	With SO_2	...	...	...	Good	...	253
329	S32900	...	...	...	400 (752)	...	Resistant	...	253
329	S32900	...	With CO_2	...	...	...	Resistant	...	253
329	S32900	...	With SO_2	...	...	...	Resistant	...	253
347	S34700	...	...	...	400 (752)	...	Resistant	...	253
347	S34700	...	With CO_2	...	...	...	Resistant	...	253
347	S34700	...	With SO_2	...	...	...	Good	...	253
403	S40300	...	...	...	400 (752)	...	Resistant	...	253
403	S40300	...	With CO_2	...	...	...	Questionable	...	253
403	S40300	...	With SO_2	...	...	...	Questionable	...	253
405	S40500	...	...	...	400 (752)	...	Resistant	...	253
405	S40500	...	With CO_2	...	...	...	Questionable	...	253
405	S40500	...	With SO_2	...	...	...	Questionable	...	253
409	S40900	...	...	...	400 (752)	...	Resistant	...	253
409	S40900	...	With CO_2	...	...	...	Questionable	...	253
409	S40900	...	With SO_2	...	...	...	Questionable	...	253
410	S41000	...	...	...	400 (752)	...	Resistant	...	253
410	S41000	...	Plus air, refluxed	...	...	...	Good	...	121
410	S41000	...	With CO_2	...	...	...	Questionable	...	253
410	S41000	...	With SO_2	...	...	...	Questionable	...	253
416	S41600	...	...	...	400 (752)	...	Resistant	...	253
416	S41600	...	With CO_2	...	...	...	Questionable	...	253
416	S41600	...	With SO_2	...	...	...	Questionable	...	253
420	S42000	...	...	...	400 (752)	...	Resistant	...	253
420	S42000	...	With CO_2	...	...	...	Questionable	...	253
420	S42000	...	With SO_2	...	...	...	Questionable	...	253
430	S43000	...	...	...	400 (752)	...	Resistant	...	253
430	S43000	...	With CO_2	...	...	...	Questionable	...	253
434	S43400	...	...	...	400 (752)	...	Resistant	...	253
F51	S31803	...	...	...	400 (752)	...	Resistant	...	253
F51	S31803	...	With CO_2	...	...	...	Resistant	...	253
F51	S31803	...	With SO_2	...	...	...	Resistant	...	253



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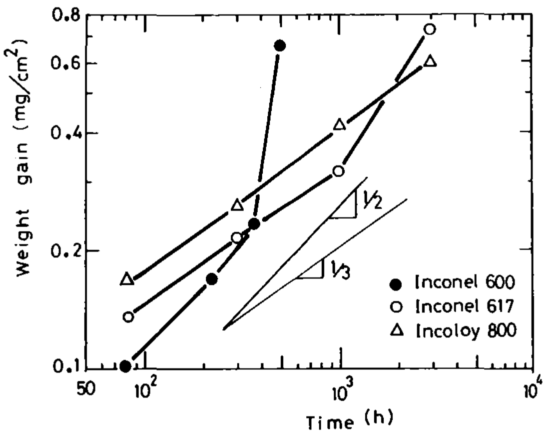
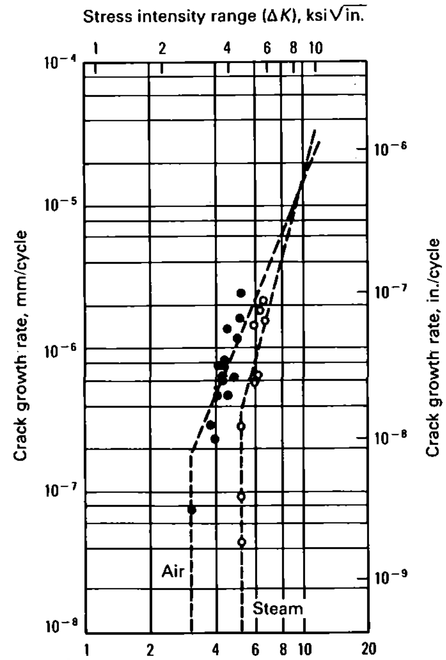
Copper. Weight loss vs. time curves for various copper alloys exposed to the steam-side environment of a condenser. The plant is located on Lake Michigan. The condenser pH averaged 9.15 to 9.30, and the average hot well oxygen concentration was approximately 25 to 50 ppb. The water temperature of the hot well was approximately 78 to 80 °F. Source: G.P. Sheldon and N.W. Polan, Field Testing of Power Utility Condenser Tube Alloys, *Journal of Material for Energy Systems*, Vol 6, Mar 1986, 314.



Heat-resisting alloys. Log-log plots of weight gain curves of Inconel 600, Inconel 617, and Incoloy 800 in steam at 800 °C and 40 atm. Source: F. Abe and H. Yoshida, Corrosion Behaviours of Heat Resisting Alloys in Steam at 800 °C and 40 atm Pressure, *Zeitschrift fur Metallkunde*, Vol 76, Mar 1985, 219-225.



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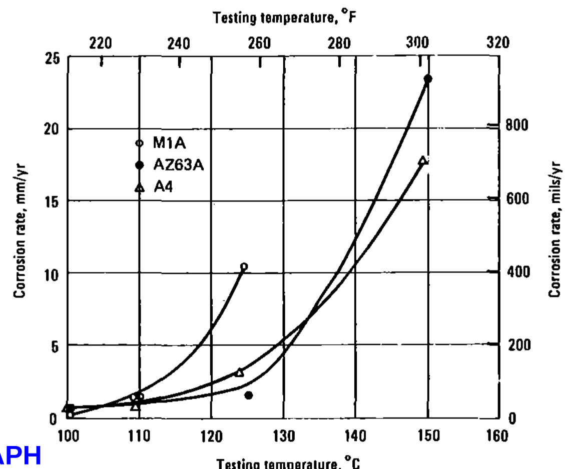
Steel. Corrosion fatigue crack propagation in ASTM A471 steel exposed to moist air and steam. Temperature: 100 °C (212 °F); frequency: 100 Hz; stress ratio: $R = 0.35$. Source: L.K.L. Tu and B.B. Seth, Threshold Corrosion Fatigue Crack Growth in Steels, *Journal of Testing and Evaluation*, Vol 6, 1978, 66-74.



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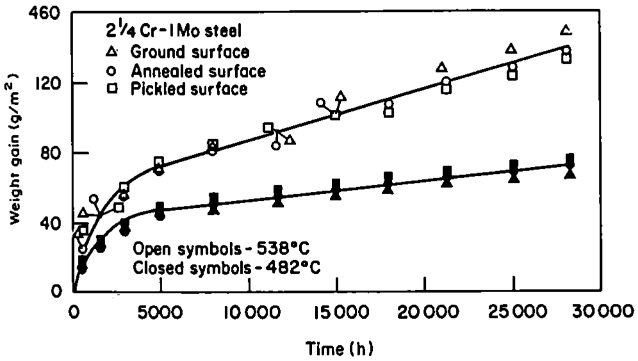
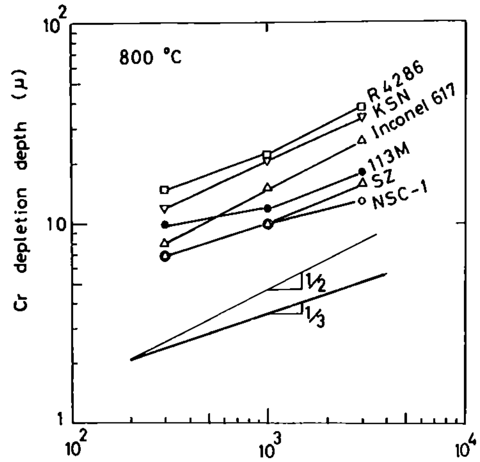
Magnesium. Effects of temperature on corrosion rates of magnesium alloys M1A, AZ63A, and A4 in steam. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 602.



Steel. Weight gains for 2.25Cr-1Mo steel exposed to superheated steam at 10.5 MPa. Source: J. Stringer, Performance Limitations in Electric Power Generating Systems Imposed by High-Temperature Corrosion, *High Temperature Technology*, Vol 3, Aug 1985, 129.



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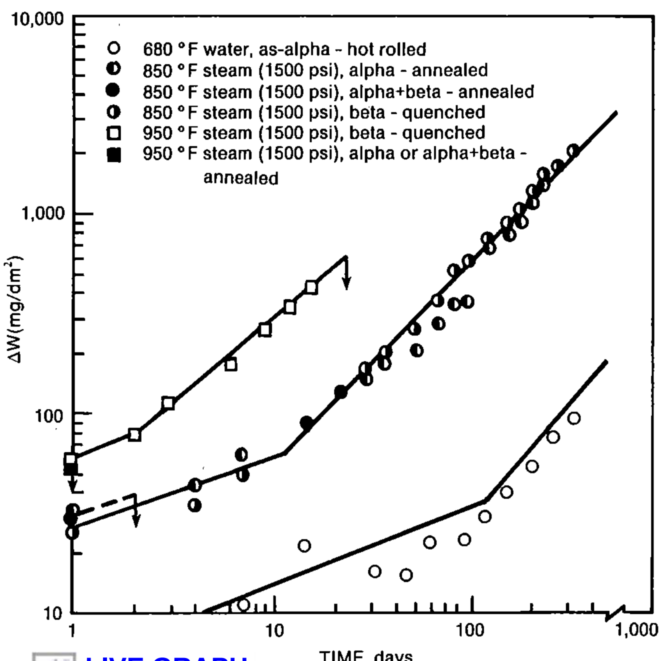
Nickel alloys. Depth of chromium-depleted zone beneath the Cr_2O_3 scale of nickel alloys in steam at 800 °C and 40 atm, as a function of exposure time. Source: F. Abe, H. Araki, *et al.*, Corrosion Behavior of Nickel Base Heat Resisting Alloys for Nuclear Steelmaking System in High-Temperature Steam, *Transactions of the Iron and Steel Institute of Japan*, Vol 25, May 1985, 427.



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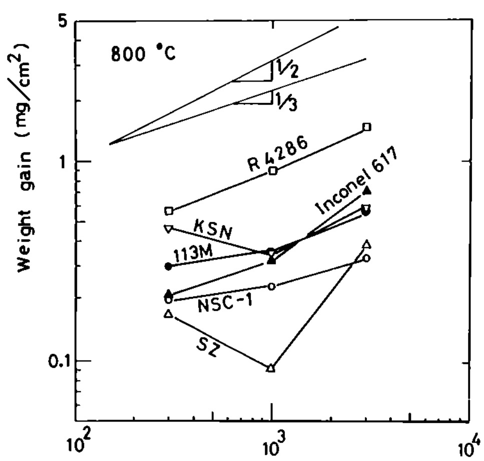
Zirconium. Corrosion of nickel-free Zircaloy-2. Source: Stanley Kass, The Development of the Zircaloys, in *Corrosion of Zirconium Alloys* (STP 368), ASTM, Philadelphia, 1964, 19.



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Nickel alloys. Weight gain curves for nickel alloys in steam at 800 °C and 40 atm. Also shown are reference lines with slopes of 1/2 and 1/3, corresponding to parabolic and cubic rate laws, respectively. Source: F. Abe, H. Araki, *et al.*, Corrosion Behavior of Nickel Base Heat Resisting Alloys for Nuclear Steelmaking System in High-Temperature Steam, *Transactions of the Iron and Steel Institute of Japan*, Vol 25, May 1985, 426.

Stearic Acid

Stearic acid, $CH_3(CH_2)_{16}COOH$, is a white or colorless, waxlike solid with a melting point of 70 °C (158 °F), and a boiling point of 232 °C (450 °F) at 2 kPa. It is soluble in alcohol, ether, and chloroform, and is insoluble in water. Stearic acid, nature's most common fatty acid, is derived from natural animal and vegetable fats. Also known as *n*-octadecanoic acid, stearic acid is used in the preparation of metallic stearates, as a lubricant, and in pharmaceuticals, cosmetics, candles, and food packaging.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy equipment has been used for steam distillation, filtration, and storage of stearic acid. In laboratory tests conducted in 100% relative humidity and ambient temperature, aluminum alloys 3003 and 5154 resisted solid stearic acid.

Copper. In the presence of moisture and air, stearic acid, like all other fatty acids, attacks copper and copper alloys. The rate of attack is also influenced by temperature and the presence of impurities. Tests made at 25 to 100 °C (75 to 212 °F) in stearic acid showed corrosion rates of C11000, C26000, and C65500 to be in the range of 500 to 1250 m/yr (20 to 50 mils/yr)

Corrosion Behavior of Various Metals and Alloys in Stearic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Questionable	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	...	Pure	Boiling	...	0.05 (2) max	...	8
Magnesium	...	...	Dry	100	Room	...	Resistant	...	119
Silver	P07010	...	...	Pure	160 (320)	...	0.05 (2) max	...	4
Silver	P07010	...	...	Pure	160 (320)	...	0.05 (2) max	...	4
Refractory metals and alloys									
Titanium	...	...	Molten	100	180 (356)	...	0.003 (0.12)	...	90
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	130 (266)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Stearic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	130 (266)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	130 (266)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	130 (266)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	130 (266)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	130 (266)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	130 (266)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	130 (266)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	130 (266)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	130 (266)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	130 (266)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	130 (266)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	130 (266)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	130 (266)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	130 (266)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	130 (266)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	130 (266)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	130 (266)	...	Resistant	...	253
Ferralium 255	S32550	...	Plus 1% H_2SO_4	...	100 (212)	...	0.21 (8.3)	...	60
Ferralium 255	S32550	...	Plus 1% H_2SO_4 and 3% NaCl	...	100 (212)	...	0.01 (0.4)	...	60
Ferralium 255	S32550	...	Plus 3% NaCl	...	100 (212)	...	0.01 (0.3) max	...	60

Succinic Acid

Succinic acid, $CO_2H(CH_2)_2CO_2H$, also known as butanedioic acid, butane diacid, and amber acid, is a colorless crystalline solid that melts at 185 °C (364 °F). Soluble in water and alcohol, it is used as a chemical intermediate. Succinic acid is used in lacquers, medicine, dyes, and as a taste modifier.

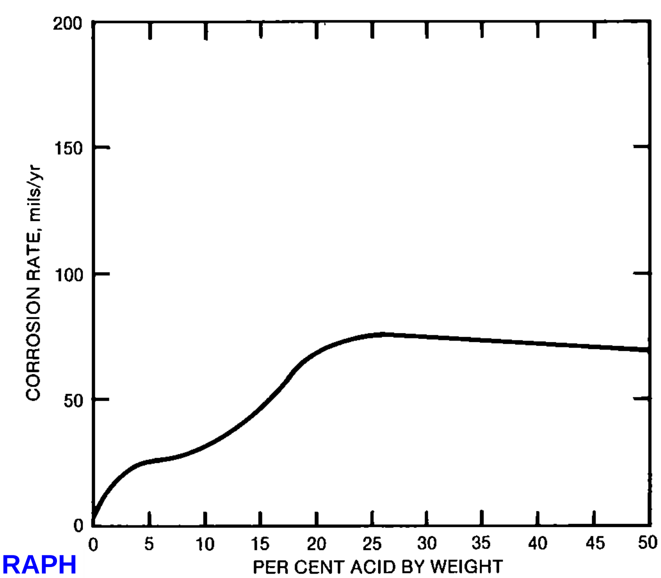
Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Under laboratory conditions of ambient temperature and 100% relative humidity, aluminum alloys 3003 and 5154 resisted solid succinic acid. Aqueous solutions of succinic acid (0.25 to 50%) caused attack of alloy 1100 that increased with concentration and temperature. In laboratory tests at 100 °C (212 °F), the attack was moderate (~6 mils/yr) at 0.25% concentration, whereas at 50% it was corrosive.

Corrosion Behavior of Various Metals and Alloys in Succinic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20-100 (68-212)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Solution	...	20-100 (68-212)	...	Resistant	...	92
Refractory metals and alloys									
Titanium	...	...	...	100	185 (366)	...	Resistant	...	90
Titanium	...	...	...	Saturated	Room	...	Resistant	...	90
Titanium, unalloyed	...	...	...	100	185 (365)	...	.005 (0.2) max	...	218
Zr702	R60702	...	...	0-50	100 (212)	...	0.05 (2) max	...	15
Zr702	R60702	...	...	100	150 (300)	...	0.05 (2) max	...	15



LIVE GRAPH
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Aluminum. Effects of succinic acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 33.

Sulfur

Sulfur, S, is a nonmetallic element that exists in a crystalline or amorphous form and in four stable isotopes. Sulfur melts at temperatures ranging from 112.8 °C (234 °F) for the rhombic form to 120.0 °C (248 °F) for amorphous sulfur, and all forms boil at 444.7 °C (835 °F).

Sulfur occurs as free sulfur in many volcanic areas and is often associated with gypsum and limestone. It is used as a chemical intermediate and fungicide and in the vulcanization of rubber.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Carbon steel. Sulfur in the presence of water causes severe localized corrosion of steels at ambient temperature.

Aluminum. In laboratory tests, 1100 and 3003 alloys were resistant to liquid sulfur at 135 to 154 °C (275 to 310 °F). Aluminum alloy equipment has been used for the recovery and purification of sulfur, in sulfur mining equipment, buildings, freight cars, hopper cars, and conveyors.

Osmium. Osmium burns in the vapor of sulfur.

Rhodium. Rhodium in its massive form is attacked slowly by molten sulfur, but the finely divided metal may react violently.

Platinum. Platinum is resistant to sulfurous gases, even at elevated temperatures.

Tantalum. Tantalum reacts with sulfur or H_2S at red heat to form tantalum sulfide (Ta_2S_4). Tantalum sulfide is also formed when Ta_2O_5 is heated in H_2S or carbon disulfide (CS_2).

Corrosion Behavior of Various Metals and Alloys in Sulfur

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Molten	...	...	...	Poor	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	Molten	...	...	...	Poor	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Molten	...	...	...	Poor	...	93
Aluminum bronze	...	...	Dry	...	...	...	Good	...	93
Aluminum bronze	...	...	Molten	...	...	...	Poor	...	93
Ampco 8, aluminum bronze	C61300	...	Molten	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Molten	...	...	...	Poor	...	93
Brass	...	...	Dry	...	...	...	Good	...	93
Brass	...	...	Molten	...	...	...	Poor	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Molten	...	...	...	Poor	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Good	...	93
Commercial bronze	C22000	...	Molten	...	...	...	Poor	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Molten	...	...	...	Poor	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Molten	...	...	...	Poor	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Molten	...	...	...	Poor	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Molten	...	...	...	Poor	...	93
Nickel-silver	...	...	Dry	18	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Nickel-silver	...	...	Molten	18	...	...	Poor	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Molten	...	...	...	Poor	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Molten	...	...	...	Poor	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Good	...	93
Phosphor copper	C12200	...	Molten	...	...	...	Poor	...	93
Red brass	C23000	...	Dry	...	...	...	Good	...	93
Red brass	C23000	...	Molten	...	...	...	Poor	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Molten	...	...	...	Poor	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Molten	...	...	...	Poor	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Refractory metals and alloys									
Titanium	...	...	Molten	100	240 (464)	...	Resistant	...	90
Stainless steels									
301	S30100	...	Dry	Boiling	445 (833)	...	Questionable	...	253
301	S30100	...	Molten	...	130 (266)	...	Resistant	...	253
301	S30100	...	Wet	...	20 (68)	...	Good	...	253
302	S30200	...	Dry	Boiling	445 (833)	...	Questionable	...	253
302	S30200	...	Molten	...	130 (266)	...	Resistant	...	253
302	S30200	...	Wet	...	20 (68)	...	Good	...	253
303	S30300	...	Dry	Boiling	445 (833)	...	Poor	...	253
303	S30300	...	Dry	Boiling	445 (833)	...	Questionable	...	253
303	S30300	...	Molten	...	130 (266)	...	Resistant	...	253
303	S30300	...	Molten	...	130 (266)	...	Resistant	...	253
303	S30300	...	Wet	...	20 (68)	...	Good	...	253
303	S30300	...	Wet	...	20 (68)	...	Good	...	253
304	S30400	...	Dry	Boiling	445 (833)	...	Questionable	...	253
304	S30400	...	Metal processing (distillation); no aeration. Liquid, plus selenium	...	454 (850)	7.8 d	0.38 (15)	...	89
304	S30400	...	Mining; strong aeration; rapid agitation. Liquid, plus small amounts of sulfuric acid and iron sulfate (air-sulfur interface)	...	138 (280)	13 d	0.38 (15)	...	89
304	S30400	...	Molten	...	130 (266)	...	Resistant	...	253
304	S30400	...	No aeration; no agitation. Liquid, water saturated, pressure 25 psig	...	120 (248)	8.5 d	2.24 (88)	Severe pitting	89
304	S30400	...	No aeration; no agitation. Liquid, with traces of moisture and hydrochloric acid	...	150 (302)	105 d	0.12 (4.8)	Severe pitting; crevice attack	89
304	S30400	...	No aeration; rapid agitation. With carbon over the standard maximum. Liquid, plus iron and aluminum chlorides, approx. 600 ppm, hydrochloric acid trace possible; filter	...	135 (275)	83 d	0.09 (3.7)	Severe pitting; crevice attack	89
304	S30400	...	Rapid agitation. Vapors	...	571 (1060)	54 d	0.68 (27)	...	89
304	S30400	...	Wet	...	20 (68)	...	Good	...	253
304L	S30403	...	Dry	Boiling	445 (833)	...	Questionable	...	253
304L	S30403	...	Molten	...	130 (266)	...	Resistant	...	253
304L	S30403	...	Wet	...	20 (68)	...	Good	...	253
304LN	S30453	...	Dry	Boiling	445 (833)	...	Questionable	...	253
304LN	S30453	...	Molten	...	130 (266)	...	Resistant	...	253
304LN	S30453	...	Wet	...	20 (68)	...	Good	...	253
316	S31600	...	Dry	Boiling	445 (833)	...	Questionable	...	253
316	S31600	...	Metal processing (distillation); no aeration. Liquid, Plus selenium	...	454 (850)	7.8 d	0.2 (8)	...	89

(Continued)

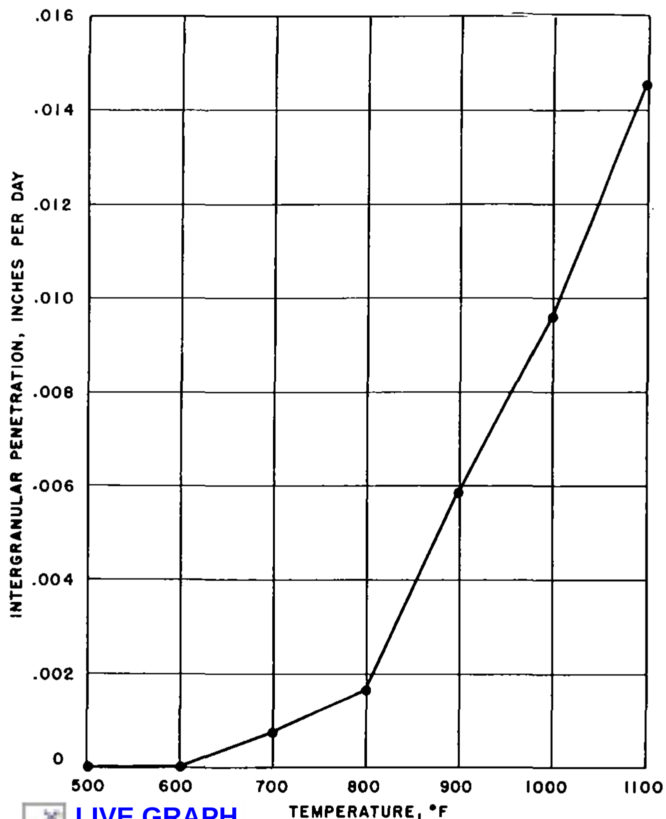
Corrosion Behavior of Various Metals and Alloys in Sulfur (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Mining; strong aeration; rapid agitation; Liquid, plus small amounts of sulfuric acid and iron sulfate (air-sulfur interface)	...	138 (280)	13 d	0.46 (18)	...	89
316	S31600	...	Molten	...	130 (266)	...	Resistant	...	253
316	S31600	...	No aeration; no agitation. Liquid with traces of moisture and hydrochloric acid	...	150 (302)	105 d	0.08 (3.3)	Severe pitting; crevice attack	89
316	S31600	...	No aeration; rapid agitation. Liquid plus iron and aluminum chlorides, approx. 600 ppm, hydrochloric acid trace possible; filter	...	135 (275)	83 d	0.06 (2.4)	...	89
316	S31600	...	No aeration; no agitation. Liquid, water saturated, pressure 25 psig	...	120 (248)	8.5 d	1.47 (58)	Severe pitting	89
316	S31600	...	Rapid agitation. Vapors	...	571 (1060)	54 d	0.79 (31)	...	89
316	S31600	...	Wet	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Dry	Boiling	445 (833)	...	Questionable	...	253
316F	S31620	...	Molten	...	130 (266)	...	Resistant	...	253
316F	S31620	...	Wet	...	20 (68)	...	Good	...	253
316L	S31603	...	Dry	Boiling	445 (833)	...	Questionable	...	253
316L	S31603	...	Molten	...	130 (266)	...	Resistant	...	253
316L	S31603	...	Wet	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Dry	Boiling	445 (833)	...	Questionable	...	253
316LN	S31653	...	Molten	...	130 (266)	...	Resistant	...	253
316LN	S31653	...	Wet	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Dry	Boiling	445 (833)	...	Questionable	...	253
316Ti	S31635	...	Molten	...	130 (266)	...	Resistant	...	253
316Ti	S31635	...	Wet	...	20 (68)	...	Resistant	...	253
317	S31700	...	Mining; strong aeration; rapid agitation; Liquid, plus small amounts of sulfuric acid and iron sulfate (air-sulfur interface)	...	138 (280)	13 d	0.43 (17)	...	89
317	S31700	...	No aeration; rapid agitation. Liquid plus iron and aluminum chlorides, approx. 600 ppm, hydrochloric acid trace possible; filter	...	135 (275)	83 d	0.08 (3.3)	...	89
317L	S31703	...	Dry	Boiling	445 (833)	...	Questionable	...	253
317L	S31703	...	Molten	...	130 (266)	...	Resistant	...	253
317L	S31703	...	Wet	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Dry	Boiling	445 (833)	...	Questionable	...	253
317LN	S31725	...	Molten	...	130 (266)	...	Resistant	...	253
317LN	S31725	...	Wet	...	20 (68)	...	Resistant	...	253
321	S32100	...	Dry	Boiling	445 (833)	...	Questionable	...	253
321	S32100	...	Molten	...	130 (266)	...	Resistant	...	253
321	S32100	...	Wet	...	20 (68)	...	Good	...	253
329	S32900	...	Dry	Boiling	445 (833)	...	Questionable	...	253
329	S32900	...	Molten	...	130 (266)	...	Resistant	...	253
329	S32900	...	Wet	...	20 (68)	...	Resistant	...	253
347	S34700	...	Dry	Boiling	445 (833)	...	Questionable	...	253
347	S34700	...	Molten	...	130 (266)	...	Resistant	...	253
347	S34700	...	Wet	...	20 (68)	...	Good	...	253
403	S40300	...	Dry	Boiling	445 (833)	...	Poor	...	253
403	S40300	...	Molten	...	130 (266)	...	Resistant	...	253
405	S40500	...	Dry	Boiling	445 (833)	...	Poor	...	253
405	S40500	...	Molten	...	130 (266)	...	Resistant	...	253
409	S40900	...	Dry	Boiling	445 (833)	...	Poor	...	253
409	S40900	...	Molten	...	130 (266)	...	Resistant	...	253
410	S41000	...	Dry	Boiling	445 (833)	...	Poor	...	253
410	S41000	...	Molten	...	130 (266)	...	Resistant	...	253
416	S41600	...	Dry	Boiling	445 (833)	...	Poor	...	253
416	S41600	...	Molten	...	130 (266)	...	Resistant	...	253
420	S42000	...	Dry	Boiling	445 (833)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	Molten	...	130 (266)	...	Resistant	...	253
430	S43000	...	Dry	Boiling	445 (833)	...	Poor	...	253
430	S43000	...	Molten	...	130 (266)	...	Resistant	...	253
430	S43000	...	Wet	...	20 (68)	...	Good	...	253
434	S43400	...	Dry	Boiling	445 (833)	...	Poor	...	253
434	S43400	...	Molten	...	130 (266)	...	Resistant	...	253
AM-363	S36300	...	...	...	Room	...	Resistant	...	120
Carpenter 20	...	...	Metal processing (distillation); field or pilot plant test; no aeration. Plus selenium	Liquid	454 (850)	7.8 d	0.7 (28)	...	89
Carpenter 20	...	...	Mining; strong aeration; rapid agitation; Plus small amounts of sulfuric acid and iron sulfate (air-sulfur interface)	Liquid	138 (280)	13 d	0.4 (15)	...	89
Carpenter 20	...	...	No aeration; rapid agitation, cast specimens. Plus iron and aluminum chlorides, approx. 600 ppm, hydrochloric acid trace possible; filter	Liquid	135 (275)	83 d	0.10 (4)	...	89
F51	S31803	...	Dry	Boiling	445 (833)	...	Questionable	...	253
F51	S31803	...	Molten	...	130 (266)	...	Resistant	...	253
F51	S31803	...	Wet	...	20 (68)	...	Resistant	...	253



LIVE GRAPH
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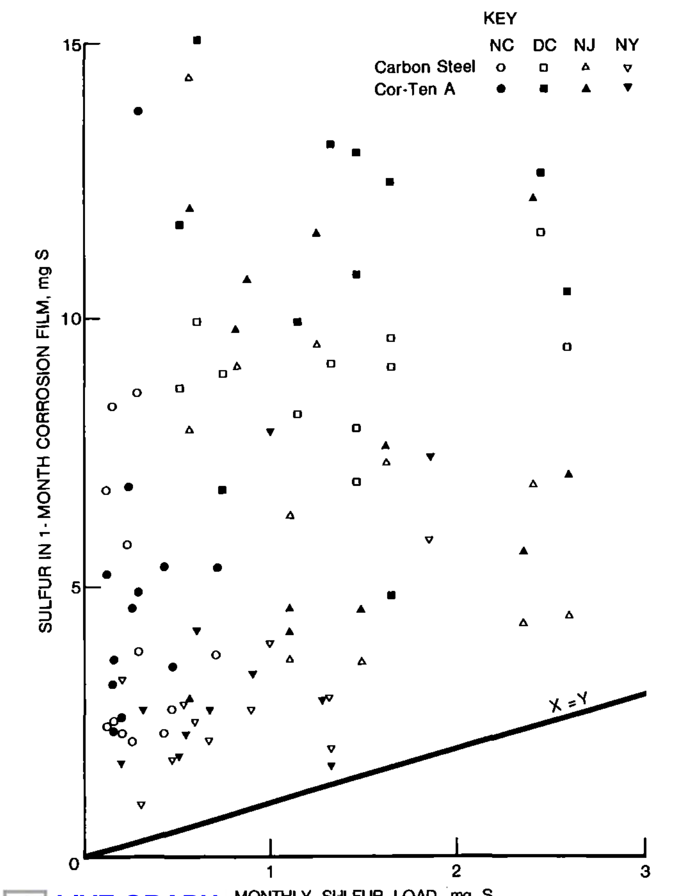
Nickel. Effect of temperature on the intergranular penetration of nickel by sulfur from Ni_3S_2 vapor. Based on 23-h tests. Source: W.Z. Friend, *Corrosion of Nickel and Nickel-Base Alloys*, John Wiley & Sons, New York, 1980, 72.



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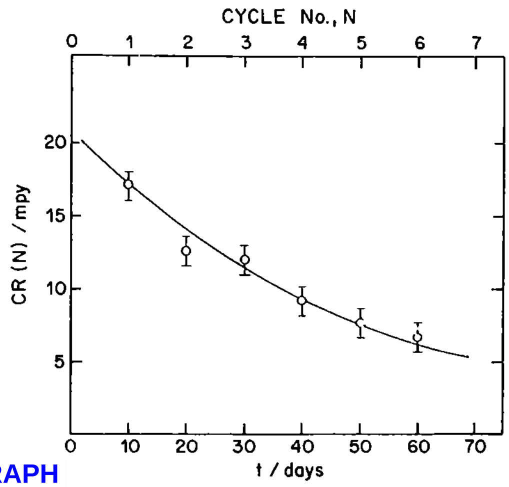
Carbon steel. Total amount of sulfur in 1-month corrosion films formed on carbon steel and Cor-Ten A compared to the amount of sulfur delivered to the samples by wet deposition during the exposure period. Exposures were made at four sites in 1983. Source: D.R. Flinn, S.D. Cramer, *et al.*, Field Exposure Study for Determining the Effects of Acid Deposition on the Corrosion and Deterioration of Materials: Description of the Program and Preliminary Results, in *Durability of Building Materials*, Vol 3, 1985, 171.



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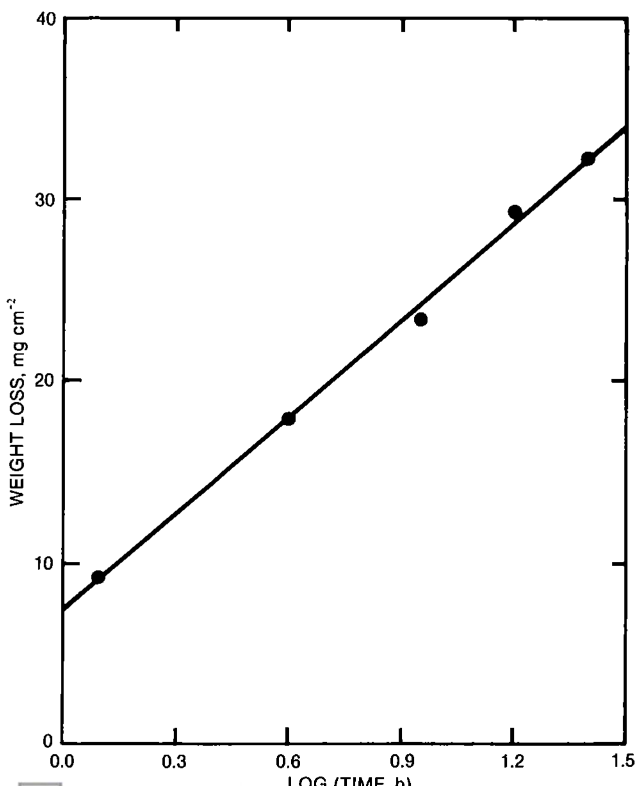
Carbon steel. Plot of the integral corrosion rate, CR(N), as a function of time and cycle number for the cyclical exposure of carbon steel to wet elemental sulfur (4 days) and the atmosphere (6 days). Source: D.D. MacDonald, B. Roberts, and J.B. Hyne, Corrosion of Carbon Steel During Cyclical Exposure to Wet Elemental Sulfur and the Atmosphere, *Corrosion Science*, Vol 18, 501, 1978.



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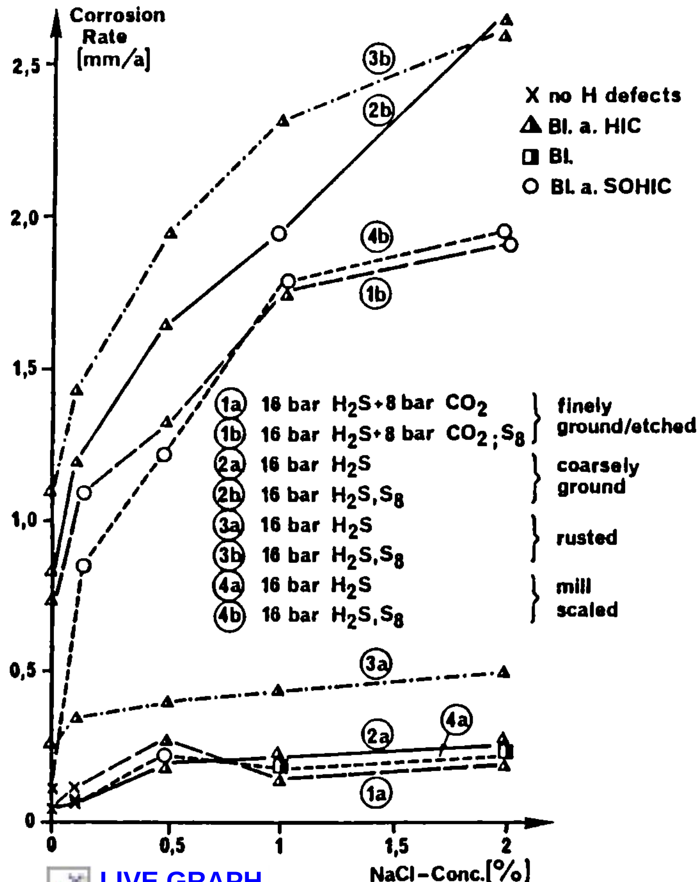
Nickel. The corrosion behavior of nickel in sulfur plotted as weight loss vs. the logarithm of time at 350 °C. Source: A.P. Brown and J.E. Battles, Corrosion of Nickel-200 and AISI-1008 Steel in Sodium Polysulfides and Sulfur at 350 °C, *Journal of the Electrochemical Society*, Vol 133, 1986, 1323.



LIVE GRAPH
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Steel. Effect of sodium chloride concentration and presence of solid elemental sulfur on corrosion behavior of stressed coupons of steel with different surface status, filmed with triethylene glycol solutions (10% water) and exposed to 16 bar H_2S + 8 bar CO_2 at 25 °C. Bl = visible blisters on surface areas of the specimens exposed to the liquid and to the gas phase of the corrosive environment. HIC = surface-parallel internal hydrogen-induced cracks observed in metallographic sections. SOHIC = stress-oriented hydrogen-induced cracks (combination of HIC and HSCC). Source: W. Bruckhoff, O. Geier, K. Hofbauer, G. Schmitt, and D. Steinmetz, "Rupture of a Sour Gas Line Due to Stress Oriented Hydrogen Induced Cracking Failure Analyses, Experimental Results and Corrosion Prevention," *Corrosion 85*, National Association of Corrosion Engineers, Houston, March 1985.

Sulfur Dioxide

Sulfur dioxide, SO_2, also known as sulfurous acid anhydride, is a toxic, irritating, colorless gas. It is soluble in water, alcohol, and ether, and boils at −10 °C. Sulfur dioxide is used as a chemical intermediate, in artificial ice, in paper pulping, in ore refining, and as a solvent.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Conventional austenitic stainless steels have been used in sulfite digestors, and types 316 and 317 stainless steels, 20Cb-3, and ACI CF-8M and CN-7M have seen service in wet sulfur dioxide and H_2SO_3 environments.

Aluminum. In laboratory tests, sulfur dioxide saturated with water was corrosive to all aluminum alloys at ambient temperature. Aluminum alloy equipment has been used for refrigeration systems containing sulfur dioxide, for heat exchangers in cooling sulfur dioxide, and for reactors converting sulfur dioxide to sulfur trioxide.

Copper. Gases containing sulfur dioxide attack copper in a manner similar to oxygen. The dry gas does not corrode copper or copper alloys, but the moist gas reacts to produce a mixture of oxide and sulfide scale. Brass is susceptible to stress-corrosion cracking in moist air containing 0.05 to 0.5 vol% sulfur dioxide.

Magnesium. Dry, gaseous sulfur dioxide causes no attack of magnesium at ordinary temperatures. If water vapor is present, some corrosion may occur. Wet (below dew point) sulfur dioxide gas is severely corrosive to magnesium due to the formation of sulfurous and sulfuric acids. It has been shown that the effects of sulfur dioxide pollution on the atmospheric corrosion of alloys ZK61A and AZ80A may cause corrosion rates of these alloys in industrial atmospheres to be somewhat higher than those found in marine atmospheres.

Niobium. At 100 °C (212 °F), niobium is inert in sulfur dioxide (wet or dry).

Gold. Gold is resistant to sulfur dioxide (wet or dry) at temperatures up to 600 °C (1110 °F).

Iridium. Iridium is resistant to wet or dry gaseous sulfur dioxide up to 1000 °C (1830 °F) if elemental sulfur is not present.

Rhodium. Rhodium is resistant to wet or dry gaseous sulfur dioxide vapors up to 1000 °C (1830 °F) if elemental sulfur is not present.

Silver. At red heat, sulfur dioxide (and sulfur trioxide) rapidly attacks silver. This attack becomes progressively worse with temperatures beginning at or near room temperature.

Tantalum. In spite of the scarcity of published data, it is to be expected that tantalum would react at some elevated temperature with oxygen-containing gaseous compounds such as sulfur dioxide.

Tin. Materials containing sulfur dioxide as a preservative produce sulfide stains on tin, but the rate of metal loss is low.

Titanium. The oxide film on titanium alloys provides an effective barrier to attack by most gases in wet or dry conditions, including sulfur dioxide. This protection extends to temperatures in excess of 150 °C (300 °F).

Zinc. Sulfur dioxide has a corrosive action on zinc because water-soluble and hygroscopic salts are formed.

Zirconium. Zirconium is stable in sulfur dioxide at temperatures as high as 300 to 400 °C (570 to 750 °F).

Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Dry gas	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	Dry gas	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
70-30 cupronickel	C71500	...	Moist	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Good	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum bronze	C61800	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	36 d	1.2 (46)	...	110
Ampco 8, aluminum bronze	C61300	...	Dry	...	...	...	0.5 (20) max	...	96
Ampco 8, aluminum bronze	C61300	...	Wet	...	...	...	0.5 (20) min	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Poor	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Good	...	93
Bronze (90Cu-10Sn)	C52400	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	1.0 (39)	...	110
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Poor	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Poor	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Poor	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Poor	...	93
Nickel bronze (88.5Cu-5Sn-5Ni-1.5Si)	C94700	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	3.1 (125)	...	110
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Questionable	...	93
Nickel-silver 55-18	C77000	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	2.8 (112)	...	110
Nickel-silver 65-18	C74500	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	3.0 (118)	...	110
Nickel-silver 75-20	C73200	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	1.6 (63)	...	110
Phosphor bronze	C51100	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	30 d	1.3 (51)	...	110
Phosphor bronze	C52100	...	Plus 1-2% oxygen. 8% carbon	17-18	200-220 (390-430)	30 d	1.7 (68)	...	110
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Good	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Good	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Good	...	93
Silicon bronze	C65500	...	Plus 1-2% oxygen	17-18	200-220 (390-430)	...	2.2 (88)	...	110
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	Dry and wet	...	600 (1110)	...	0.05 (2) max	...	8
Gold	P00016	...	Dry and wet	...	600 (1110)	...	0.05 (2) max	...	8
Magnesium	...	...	Dry	100	Room	...	Resistant	...	119
Platinum	P04995	...	Dry and wet	...	600 (1110)	...	0.05 (2) max	...	6
Silver	P07010	...	...	Pure	Red heat	...	Poor	...	8
Nickel and alloys									
Alloy 825	N08825	...	Rapid agitation. Plus 30-80% water, 5-7% sulfur trioxide	7-10	89-93 (180-200)	4.5 d	0.5 (20)	...	89
Alloy 825	N08825	...	Strong aeration; rapid agitation. Small amount of sulfur trioxide and moisture, sulfur burner, discharge line	18	260-371 (500-700)	90 d	0.003 (0.1)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.3-0.75% sulfuric acid. Peabody scrubber	10	29-32 (85-95)	20 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid	10	52-57 (125-135)	20 d	0.05 (2)	...	89
Inconel 600	N06600	...	Molten sulfur	...	127 (260)	96 h	0.02 (0.6)	...	109
Inconel 600	N06600	...	Molten sulfur	...	296 (565)	h	0.02 (0.8)	...	109
Inconel 600	N06600	...	Molten sulfur	...	352 (665)	h	0.3 (12)	...	109
Inconel 600	N06600	...	Molten sulfur	...	366 (690)	h	0.4 (16)	...	109
Inconel 600	N06600	...	Molten sulfur	...	446 (835)	h	2.2 (86)	...	109
Monel 400	N04400	...	Molten sulfur	...	127 (260)	96 h	0.04 (1.6)	...	109
Monel 400	N04400	...	Molten sulfur	...	260 (500)	96 h	0.07 (3)	...	109
Monel 400	N04400	...	Molten sulfur	...	296 (565)	64 h	0.9 (36)	...	109
Monel 400	N04400	...	Molten sulfur	...	352 (665)	66 h	0.4 (16)	...	109
Monel 400	N04400	...	Molten sulfur	...	366 (690)	65 h	1.4 (57)	...	109
Monel 400	N04400	...	Molten sulfur	...	446 (835)	48 h	33 (1300)	...	109
Nickel 200	N02200	...	Molten sulfur	...	127 (260)	96 h	0.03 (1)	...	109
Nickel 200	N02200	...	Molten sulfur	...	260 (500)	96 h	0.3 (12)	...	109
Nickel 200	N02200	...	Molten sulfur	...	296 (565)	64 h	0.3 (13)	...	109
Nickel 200	N02200	...	Molten sulfur	...	352 (665)	66 h	8 (330)	...	109
Nickel 200	N02200	...	Molten sulfur	...	366 (690)	65 h	18 (700)	...	109
Nickel 200	N02200	...	Molten sulfur	...	446 (835)	48 h	31 (1210)	...	109
Refractory metals and alloys									
Titanium	...	...	Dry	...	21 (70)	...	Resistant	...	90
Titanium	...	...	Gas + small amount SO_3 and approx. 3% oxygen	18	316 (601)	...	0.01 (0.2)	...	90
Titanium	...	...	Water saturated	Near 100	Room	...	0.003 (0.1)	...	90
Stainless steels									
301	S30100	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
301	S30100	...	Moist, free of SO_3	...	100 min	...	Good	...	253
301	S30100	...	Moist, free of SO_3	...	300° min	...	Good	...	253
301	S30100	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
302	S30200	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
302	S30200	...	Moist, free of SO_3	...	100 min	...	Good	...	253
302	S30200	...	Moist, free of SO_3	...	300° min	...	Good	...	253
302	S30200	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
303	S30300	...	Moist, free of SO_3	...	100 (212)	...	Questionable	...	253
303	S30300	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
303	S30300	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
303	S30300	...	Moist, free of SO_3	...	100 min	...	Good	...	253
303	S30300	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
303	S30300	...	Moist, free of SO_3	...	300° min	...	Good	...	253
303	S30300	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
303	S30300	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
304	S30400	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
304	S30400	...	Moist, free of SO_3	...	100 min	...	Good	...	253
304	S30400	...	Moist, free of SO_3	...	300° min	...	Good	...	253
304	S30400	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	No aeration; rapid agitation. Plus 20% nitrogen, saturated water vapor	80	15 (60)	94 d	0.003 (0.1)	...	89
304	S30400	...	Plus air, 6% moisture, 1% sulfur trioxide	5	218 (425)	68 d	0.05 (2)	...	89
304	S30400	...	Pulp and paper processing; field or plant test. Plus moisture, small amount of sulfur trioxide, tower	13-17	38 (100)	37 d	0.003 (0.1) max	...	89
304	S30400	...	Rapid agitation. Plus 30-80% water, 5-7% sulfur trioxide	7-10	82-93 (180-200)	4.5 d	.51 (20)	...	89
304	S30400	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid	10	52-57 (125-135)	20 d	.05 (2)	Slight pitting	89
304	S30400	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid	10	52-57 (125-135)	20 d	6.45 (254)	Slight pitting	89
304	S30400	...	Sulfuric acid processing; strong aeration; rapid agitation. With carbon over the standard maximum. Approx. 10% water saturated, recycle liquor contains 0.3-0.75% sulfuric acid. Peabody scrubber	10	29-32 (85-95)	20 d	0.003 (0.1)	...	89
304L	S30403	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
304L	S30403	...	Moist, free of SO_3	...	100 min	...	Good	...	253
304L	S30403	...	Moist, free of SO_3	...	300° min	...	Good	...	253
304L	S30403	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
304LN	S30453	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
304LN	S30453	...	Moist, free of SO_3	...	100 min	...	Good	...	253
304LN	S30453	...	Moist, free of SO_3	...	300° min	...	Good	...	253
304LN	S30453	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
316	S31600	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
316	S31600	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
316	S31600	...	Moist, free of SO_3	...	300° min	...	Good	...	253
316	S31600	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
316	S31600	...	No aeration; rapid agitation. Plus 20% nitrogen, saturated water vapor	80	15 (60)	94 d	0.008 (0.3)	...	89
316	S31600	...	Plus air, 6% moisture, 1% sulfur trioxide	5	218 (425)	68 d	.05 (2)	...	89
316	S31600	...	Pulp and paper processing. Plus moisture, small amount of sulfur trioxide, towe	13-17	38 (100)	37 d	0.003 (0.1) max	...	89
316	S31600	...	Rapid agitation. Plus 30-80% water, 5-7% sulfur trioxide	7-10	82-93 (180-200)	4.5 d	.53 (21)	...	89
316	S31600	...	Strong aeration; rapid agitation. Small amount of sulfur trioxide and moisture, sulfur burner, discharge line	18	260-371 (500-700)	90 d	.005 (0.2)	...	89
316	S31600	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.3-0.75% sulfuric acid, Peabody scrubber	10	29-32 (85-95)	20 d	0.003 (0.1)	...	89

(Continued)

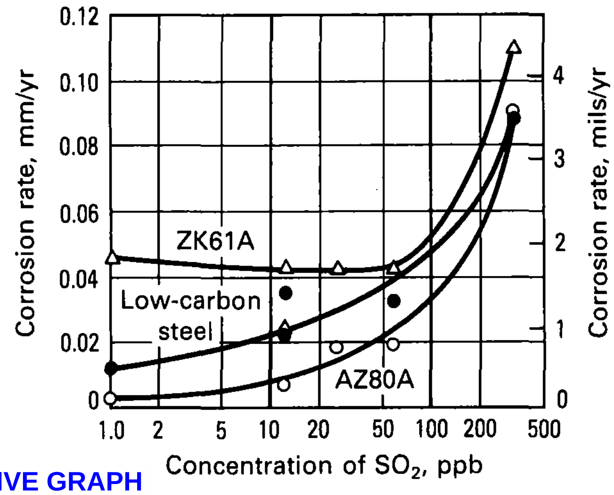
Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid	10	52-57 (125-135)	20 d	1.32 (52)	...	89
316F	S31620	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
316F	S31620	...	Moist, free of SO_3	...	100 min	...	Good	...	253
316F	S31620	...	Moist, free of SO_3	...	300° min	...	Good	...	253
316F	S31620	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
316L	S31603	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
316L	S31603	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
316L	S31603	...	Moist, free of SO_3	...	300° min	...	Good	...	253
316L	S31603	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
316LN	S31653	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
316LN	S31653	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
316LN	S31653	...	Moist, free of SO_3	...	300° min	...	Good	...	253
316LN	S31653	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
316Ti	S31635	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
316Ti	S31635	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
316Ti	S31635	...	Moist, free of SO_3	...	300° min	...	Good	...	253
316Ti	S31635	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
317	S31700	...	Pulp and paper processing. Plus moisture, small amount of sulfur trioxide, tower	13-17	38 (100)	37 d	0.003 (0.1) max	...	89
317	S31700	...	Strong aeration; rapid agitation. Small amount of sulfur trioxide and moisture, sulfur burner, discharge line	18	260-371 (500-700)	90 d	.008 (0.3)	...	89
317	S31700	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.3-0.75% sulfuric acid	10	29-32 (85-95)	20 d	0.003 (0.1)	...	89
317	S31700	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid, Peabody scrubber	10	52-57 (125-135)	20 d	0.15 (6)	...	89
317L	S31703	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
317L	S31703	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
317L	S31703	...	Moist, free of SO_3	...	300° min	...	Good	...	253
317L	S31703	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
317LN	S31725	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
317LN	S31725	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
317LN	S31725	...	Moist, free of SO_3	...	300° min	...	Good	...	253
317LN	S31725	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
321	S32100	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
321	S32100	...	Moist, free of SO_3	...	100 min	...	Good	...	253
321	S32100	...	Moist, free of SO_3	...	300° min	...	Good	...	253
321	S32100	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
329	S32900	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
329	S32900	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
329	S32900	...	Moist, free of SO_3	...	300° min	...	Good	...	253
329	S32900	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253
347	S34700	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253

(Continued)

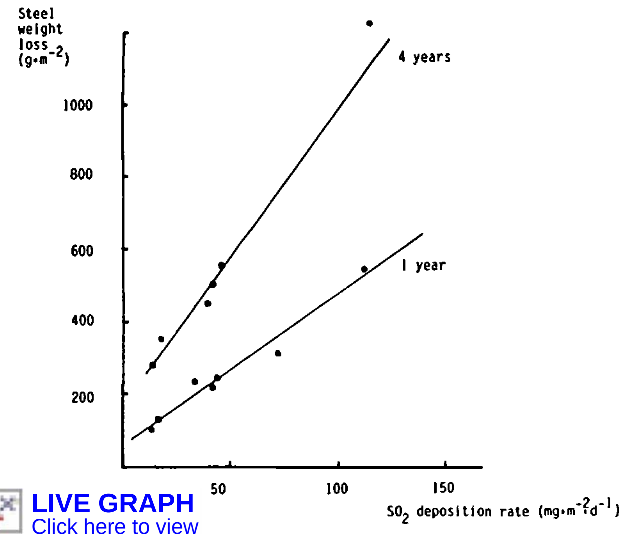
Corrosion Behavior of Various Metals and Alloys in Sulfur Dioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	Moist, free of SO_3	...	100 min	...	Good	...	253
347	S34700	...	Moist, free of SO_3	...	300° min	...	Good	...	253
347	S34700	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
403	S40300	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
403	S40300	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
403	S40300	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
403	S40300	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
405	S40500	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
405	S40500	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
405	S40500	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
405	S40500	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
409	S40900	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
409	S40900	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
409	S40900	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
409	S40900	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
410	S41000	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
410	S41000	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
410	S41000	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
410	S41000	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
416	S41600	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
416	S41600	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
416	S41600	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
416	S41600	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
420	S42000	...	Moist, free of SO_3	...	100 (212)	...	Poor	...	253
420	S42000	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
420	S42000	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
420	S42000	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
430	S43000	...	Moist, free of SO_3	...	100 (212)	...	Questionable	...	253
430	S43000	...	Moist, free of SO_3	...	100 min	...	Poor	...	253
430	S43000	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
430	S43000	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
434	S43400	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
434	S43400	...	Moist, free of SO_3	...	100 min	...	Good	...	253
434	S43400	...	Moist, free of SO_3	...	300° min	...	Poor	...	253
434	S43400	...	Moist, free of SO_3	...	900 (1652)	...	Poor	...	253
Carpenter 20	...	...	Strong aeration; rapid agitation. Small amount of sulfur trioxide and moisture, sulfur burner, discharge line	18	260-371 (500-700)	90 d	0.01 (0.2)	...	89
Carpenter 20	...	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.3-0.75% sulfuric acid. Peabody scrubber	10	29-32 (85-95)	20 d	0.003 (0.1)	...	89
Carpenter 20	...	...	Sulfuric acid processing; strong aeration; rapid agitation. Approx. 10% water saturated, recycle liquor contains 0.7-2.5% sulfuric acid	10	52-57 (125-135)	20 d	0.08 (3)	...	89
F51	S31803	...	Moist, free of SO_3	...	100 (212)	...	Resistant	...	253
F51	S31803	...	Moist, free of SO_3	...	100 min	...	Resistant	...	253
F51	S31803	...	Moist, free of SO_3	...	300° min	...	Good	...	253
F51	S31803	...	Moist, free of SO_3	...	900 (1652)	...	Questionable	...	253



LIVE GRAPH
Click here to view

Magnesium. Corrosion rates vs. sulfur dioxide pollution levels at six exposure sites. Rainfall at the sites ranged from 533 to 965 mm/yr (21 to 38 in./yr). Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 747.



LIVE GRAPH
Click here to view

Steel. Corrosion vs. sulfur dioxide deposition rate. Corrosion on a painted steel surface generally begins at a defect in the coating with an initial loss of coating adhesion through cathodic delamination. Exposure to sulfur dioxide, a common corrosion stimulator that occurs in industrial and dense population areas, tends to give a neutral-to-acid subcoating liquid. Source: L. Igetoft, Reactions on Painted Steel Under the Influence of Sulfur Dioxide, Sodium Chloride and Combinations Thereof, *Industrial and Engineering Chemistry, Product Research and Development*, Vol 24, 1985, 376.

Sulfur Trioxide

Sulfur trioxide, SO_3, also known as sulfuric anhydride, exists in a number of modifications that differ in molecular species and crystalline form. It has a white, ice-like modification that melts at 16 °C (61 °F) and two other asbestos-like forms that melt at the higher temperatures of 33 and 62 °C (90 and 144 °F). The colorless liquid or gas form has irritating, toxic fumes and boils at 45 °C (112 °F). Sulfur trioxide is a highly reactive substance, a strong oxidizing agent, and a fire hazard. It reacts with metallic oxides to form sulfates and with water to form sulfuric acid. Sulfur trioxide is used for sulfonation.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Aluminum alloy reactors have been used for converting sulfur dioxide to sulfur trioxide.

Tantalum. Tantalum is attacked, even at room temperature, by free sulfur trioxide (as in fuming sulfuric acid).

Silver. Sulfur trioxide attacks silver at room temperature. The attack becomes progressively worse with rising temperatures.

Corrosion Behavior of Various Metals and Alloys in Sulfur Trioxide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Copper and alloys									
70-30 cupronickel	C71500	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfur Trioxide (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Miscellaneous									
Silver	P07010	...	...	Pure	Red heat	...	0.05 (2) max	...	8

Sulfuric Acid

Sulfuric acid, H_2SO_4, also known as oil of vitriol and dipping acid, is a colorless, toxic, oily liquid. A great deal of heat is released when concentrated sulfuric acid and water are mixed; therefore, acid should always be added to water with sufficient stirring to prevent splattering and boiling. Sulfuric acid has a strong attraction for water and forms four crystalline hydrates. This affinity for water makes sulfuric acid an efficient drying agent for gases such as hydrogen, oxygen, nitrogen, and carbon dioxide, but results in the charring of organic compounds containing carbon, hydrogen, and oxygen such as cellulose, sugar, paper, and wood. Sulfuric acid participates in two types of oxidation reactions. One is the typical reaction of a strong acid that depends on the oxidizing power of the hydrogen ion, for example, the reaction of an active metal with the dilute acid to produce hydrogen. Sulfuric acid is a strong electrolyte and is used in electroplating baths, for pickling, and for other operations in the production of iron and steel. In the second type of oxidation reaction, the sulfate portion of the molecule reacts to form acid sulfates or bisulfates and the normal sulfates. Sulfuric acid is used in the manufacture of fertilizers, organic pigments, explosives, rayon, and film. Sulfuric acid has low volatility, a feature utilized in the manufacture of volatile acids such as nitric, hydrochloric, and hydrofluoric, where the volatile acid is vaporized when one of its salts is heated with the sulfuric acid.

Sulfuric acid is manufactured by the catalytic oxidation of sulfur dioxide by either the contact process or the lead-chamber process, although the contact process is now the primary process used to manufacture sulfuric acid. Acid produced by the conversion of sulfur trioxide by the contact process is concentrated (98 to 99%) and pure. Because anhydrous sulfuric acid is difficult to ship on account of its high freezing point, 10.5 °C (50 °F), sulfuric acid is ordinarily shipped at the 93.19% concentration, which is designated as oil of vitriol. This concentration has a low freezing point of –34 °C (–29 °F) and does not corrode steel containers at ordinary temperatures.

In the lead-chamber process, sulfur dioxide, oxygen, water vapor, and oxides of nitrogen are mixed in large, lead-lined chambers, and the liquid products as run off from the floor of the chambers is called chamber acid. Chamber acid has a concentration of 60 to 70% sulfuric acid by weight and contains considerable impurities. It reacts with steel shipping containers and is rarely shipped in quantity. Although more dilute acids are prepared, they must be shipped in expensive glass bottles. Chamber acid may be concentrated to 77% by evaporation in lead-lined pans and shipped in areas where its freezing point of –10.8 °C (12.6 °F) is acceptable. In cold climates, the concentration may be diluted to 76% to lower the freezing point. Sulfuric acid at the 76 to 78% concentration level is not seriously corrosive to steel tank cars and is an economical supply for the production of superphosphate by the fertilizer industry.

Temperature, concentration, and the presence of impurities affect the corrosiveness of sulfuric acid. Below 85% by weight at room temperature or about 65% at higher temperatures, sulfuric acid is a reducing acid

and can best be handled by materials resistant to reducing conditions. In higher concentrations, it becomes an oxidizing acid and materials resistant to oxidizing agents are required. Selection of a metal or alloy for a particular application depends on the reducing or oxidizing nature of the solution, velocity, film formation, continuity of exposure, and physical properties of the alloy. Of the common metals, only lead is acceptably resistant to cold sulfuric acid in concentrations up to 100% and hot sulfuric acid in concentrations up to 70%. Cast iron resists both hot and cold sulfuric acid because of the formation of a protective scale layer. This resistance is very dependent on the concentration, which must be over 70% for cold acid and over 90% for hot acid. Cast iron may crack with explosive violence in the presence of sulfur trioxide gas and therefore should not be used as container material for oleum unless acid-resistant linings are used. Mild steel forms the same protective layer as cast iron, but is not as resistant and should not be used at temperatures over 49 °C (120 °F). In general, cast steel and malleable iron are available for specific concentrations, temperatures, and applications. Care must be exercised to exclude moisture from any iron or steel containers to prevent dilution and subsequent rapid corrosion. Other common alloys used to service sulfuric acid are Ni-Mo (Hastelloy B), Ni-Mo-Cr (Alloy C-276), Duriron, and Durimet 20. Duriron has the necessary corrosion resistance for use in concentrated sulfuric acid at very high temperatures (up to 400 °F).

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Alloy Steel. Steel tanks are used to store sulfuric acid at ambient temperatures at concentrations of 65 to 100%. Corrosion can rapidly become catastrophic at these concentrations and at temperatures above 25 °C (75 °F).

Aluminum. Because the rate of attack is very low, aluminum alloys may be used to handle both dilute (below 10%) and concentrated (above 98%) sulfuric acid solutions. However, rapid attack occurs in the concentration range of 40 to 95%, with the maximum corrosion occurring at 80% concentration. In laboratory tests at ambient temperature, aluminum alloy 3003 suffered mild attack by fuming acids containing 101, 103, 107, and 115% sulfuric acid. Aluminum alloy 1100 pipe carries 99.5% acid at 45 °C (113 °F) in one plant. In another plant, 98% acid is transported in alloy 1100-H112 pipe at 200 °C (392 °F). Dilute solutions also utilize aluminum. For example, aluminum is used to process a thin aqueous slurry containing 1% sulfuric acid at room temperature, and an aluminum condenser cools sludge vapors from coking pots. Although the dilute sulfuric acid condensate causes some corrosion, aluminum has proved economical.

Carbon Steel. Steel has long been used in handling concentrated sulfuric acid at ambient temperatures under static and low-velocity conditions (<0.9 m/s, or 3 ft/s). A soft sulfate film forms that is highly protective unless physically disturbed. The actual corrosion rate of steel depends on temperature, acid concentration, iron content, and flow, because these parameters determine the dissolution rate of the protective sulfate film. Carbon steel corrodes in the active state at all concentrations up to 100% sulfuric acid. At concentrations below 50%, the iron sulfate corrosion product readily goes into solution, and corrosion rates are high at any temperature. At higher concentrations, the initial corrosion rate is high, but it is quickly reduced by the accumulation of iron sulfate corrosion product. It has been shown that the dissolution and diffusion of the ferrous sulfate away from the surface is the rate-limiting step. The effects of velocity, concentration, and temperature on the corrosion process in piping and storage tanks have been modeled. High velocity increases corrosion; therefore, steel is unsuitable for pump construction. At concentrations from 65 to 100% and at ambient temperatures, the sulfate layer diffuses into solution sufficiently slowly for the use of steel as a material of construction. Corrosion rates are typically 0.15 to 1.0 mm/yr (5.9 to 39 mils/yr). Storage tanks, pipelines, tank cars, and shipping drums made of ordinary carbon steel routinely handle sulfuric acid in concentrations of 78, 93, and 98%. In the oleum range above 101% sulfuric acid concentration (4% free SO_3), steel corrodes in the passive region because of the oxidizing effect of the SO_3. The passive film contains iron ions oxidized to the ferric state. Corrosion rates are typically 0.1 mm/yr (3.9 mils/yr) at ambient temperature. In the 100 to 101% concentration range, the steel goes through an active-passive transition state, and measured corrosion rates are erratic and excessive above 25 °C (75 °F). Steel is generally unsuitable in temperatures above 78 °C (175 °F).

Powder Metallurgy. In one study, potentiostatic anodic polarization measurements of steam-treated carbon steel in dilute (0.5%) sulfuric acid and aqueous sodium chloride solutions (400 ppm chloride ion) revealed significant reduction of corrosion rates for the chloride ion environment, whereas sulfuric acid testing showed an increase in corrosion rate. The latter was attributed to the solubility of the oxides in dilute sulfuric acid and their increased attack compared to the unoxidized steel.

Cast Irons. Cast iron alloys containing approximately 14.5% silicon have the best overall corrosion resistance to sulfuric acid in the 0 to 100% concentration range. Rapid attack occurs at concentrations over 100% and in service environments containing sulfur trioxide. It demonstrates good corrosion resistance (<5 mils/yr) to concentrated sulfuric acid at temperatures up to and including boiling. The resistance of high-silicon iron derives from the formation of a strong silicon-rich abrasion-resistant film that allows it to handle even the most abrasive slurries. High-silicon cast iron has been used at temperatures as high as 538 °C (1000 °F), when the temperature was raised and lowered slowly to prevent thermal shock. Duriron, a high-silicon cast iron alloy, is widely used for pumps, valves, heat exchangers, fans, tower sections, spargers, and sulfuric acid concentrator heating tubes.

High-nickel austenitic cast irons containing molybdenum exhibit acceptable corrosion resistance at room temperature and at slightly elevated temperatures. They are adequate over the entire range of sulfuric acid concentrations, but are a second choice compared to high-silicon cast irons.

Use of unalloyed and low-alloyed cast iron is limited to low-velocity, low-temperature concentrated (>70%) sulfuric acid. In a low flow velocity, concentrated sulfuric acid may form a protective coating of insoluble iron sulfate film. If the acid is diluted to concentrations below 60%, the iron sulfate becomes soluble and rapid corrosion occurs. Therefore, unalloyed cast iron is rarely used in dilute or intermediate concentrations. Ductile iron is generally considered superior to gray iron, and ferritic matrix irons are superior to pearlitic matrix irons. The graphite flakes in cast iron are detrimental in oleum service. The acid can penetrate along the graphite flakes, and the corrosion product will build up sufficient pressure to split the iron. Interconnecting graphite is believed to be necessary to cause this form of cracking; therefore, ductile and malleable irons are generally acceptable for this service. In tests at room

or moderate temperatures, iron demonstrates excellent resistance to mixtures of concentrated nitric and sulfuric acids with up to 20% water. The corrosion rate of iron in a mixture of 60% nitric and 10% sulfuric acids was 0.1 mm/yr (5 mils/yr). The iron-base superalloy Pyromet RN-155 (AISI 661, UNS R31055) has better resistance than stainless steel to dilute solutions of sulfuric acid.

Cemented Carbides. Sulfuric acid vigorously attacks the basic cemented carbides. The experimental grade 7 (WC-40TaC-3NiCoCr) provides excellent corrosion resistance. The straight WC-Co compositions experience rapid attack in warm (50 °C, or 120 °F) dilute sulfuric acid, but little attack in concentrated sulfuric acid. The Ti-6.5Ni-5Mo composition is quite good in warm sulfuric acid. Because sulfuric acid attacks the binders in cemented carbides, several of the binderless compositions and the TaC-base cemented carbides exhibit very acceptable corrosion resistance in warm sulfuric acid.

Copper Alloys. Copper and copper alloys are generally not suited for service in sulfuric acid because of their strong oxidation potentials. Brass can suffer dezincification in sulfuric acid. Normal copper-tin-bronzes may be used in concentrations below 60% at 79 °C (174 °F). Silicon bronzes such as C65500 can be used in solutions containing 3 to 70% by weight sulfuric acid at temperatures of 25 to 70 °C (75 to 160 °F). Aluminum bronzes are generally suitable for service in dilute (10 to 20%) sulfuric acid, especially in steel-pickling acids and in handling oil refinery sludges.

Zinc. The corrosion rate of zinc in sulfuric acid depends on the concentration of the acid and the impurities present in the metal. Zinc is slowly dissolved by dilute sulfuric acid, a reaction that releases hydrogen. Impurities in commercial zinc, such as aluminum, retard corrosion by the formation of a protective film. Other impurities, such as copper, reprecipitate in the form of a black metallic sponge, which may accelerate the attack by providing increased surface area. Tin and lead initially retard the corrosion rate, but after a few hours, they are deposits as metallic sponge and the corrosion rate is the same as in commercial zinc.

Lead. Lead exhibits high corrosion resistance to sulfuric acid and is used extensively in applications using concentrations below 70%. Lead has a protective film of lead sulfate that is soluble in concentrated sulfuric acid. This film is easily damaged by erosion or abrasion even at low velocities. For this reason, lead is rarely used for pumps or valves. Chemical lead, which contains 0.06% copper, is used in aggressive corrosion applications. Tellurium lead resists hot concentrated acid, but is inferior to chemical lead in all other conditions according to laboratory tests and plant data. Hard lead (4 to 15% antimony) is used when superior strength is required in dilute acid conditions. Lead is used as a pan material to catch acid drippings and as a membrane behind brick in sulfuric acid concentrating and scrubbing units.

Metallic Glasses. Copper-zirconium alloys have excellent resistance to sulfuric acid when they are devitrified to a single-phase or a multiphase equilibrium microstructure. However, the glassy state was about 20% more corrosion resistant than the devitrified state. The corrosion rates of the glassy alloy system containing phosphorus as the major metalloid were two orders of magnitude lower than those of the alloy system with boron as the major metalloid. In addition, the corrosion rate of the glassy iron-chromium alloy progressively decreased by the addition of silicon, boron, carbon, and phosphorous in 0.1*N* sulfuric acid. The additicn of chromium without phosphorus to glassy alloys is relatively ineffective in reducing corrosion rates.

Nickel. Nickel 200 can be used in sulfuric acid solutions at low or moderate temperatures. Aeration, increasing temperature, and the presence of oxidizing salts increase corrosion rates. The corrosion rate of Nickel 200 in boiling 5% sulfuric acid is 34 mils/yr, whereas in 10% boiling sulfuric acid it is 120 mils/yr. These corrosion rates could be lowered by either boiling under vacuum where the temperatures would be reduced or by the addition of inhibitors.

Nickel-Base Alloys. The corrosion rates of nickel-base alloys, in general, increase with acid concentrations up to about 90 wt%. However, the determining factor is the molybdenum and chromium content in the alloy composition. Higher concentrations of the acid are generally less corrosive. At low acid concentrations, the nickel-chromium-molybdenum alloys, such as Alloy C-276, show significantly higher resistance than type 316 stainless steel. Alloy 20, a high-nickel stainless steel, shows similar behavior. These high nickel-chromium-molybdenum alloys can be used only at moderate temperatures in intermediate and high concentrations of sulfuric acid. The nickel-molybdenum Alloy B-2 performs well in pure, deaerated sulfuric acid; however, in the presence of oxidizing species (ferric ions) and oxygen (air), it suffers serious corrosion.

The presence of oxidizing impurities can be beneficial to nickel-chromium-molybdenum alloys because these impurities can aid in the formation of passive films that retard corrosion. Another important consideration is the presence of chlorides. Chlorides generally accelerate the attack. Therefore, high-molybdenum alloys are used in the production of mineral acids when the acid is contaminated with halides. These alloys are also specified when sulfuric acid is used in the production of other chemicals and for the construction of radioactive waste disposal evaporators.

Some nickel-base alloys have superior resistance to corrosion in sulfuric acid up to 95% concentration because of their high alloy content, e.g., Alloy C-276 and Alloy 625. Frequently, low corrosion rates occur in both the active and passive states. Thus, reliable corrosion behavior is achieved over a wide range of concentrations, temperatures, and impurity levels.

Nickel-copper alloys, for example, Monel 400, are used to handle sulfuric acid under reducing conditions. This alloy offers an alternative to stainless steels and other alloys exhibiting active-passive behavior when the sulfuric acid solutions are nonoxidizing such as deaerated dilute acid. Monel 400 has low corrosion rates in air-free sulfuric acid up to 85% concentration at 30 °C (85 °F) and up to 60% concentration at 95 °C (205 °F). In air-saturated acid, increasing the temperature or the velocity accelerates the corrosion rate considerably.

Inconel 600, because of its high chromium content, has better resistance to sulfuric acid under oxidizing conditions than either Nickel 200 or Monel 400. Although Inconel 600 may be passivated by the addition of oxidizing salts, it should not be subjected to hot sulfuric acid except in low concentrations. When aeration is combined with high temperature, corrosion rates are high. Both Chlorimet 3 and Hastelloy C are useful in all concentrations of sulfuric acid. They exhibit good resistance to hot dilute acids under reducing conditions and, because of their high chromium contents, are not affected by oxidizing conditions. Alloy 617 is resistant to sulfuric acid in concentrations of 30% at 80 °C (175 °F) and 10% at boiling.

Nickel-base iron-chromium-molybdenum-copper alloys, such as Incoloy 825, provide excellent service in applications where chlorides are present. Incoloy 825 is highly resistant to all concentrations of sulfuric

acid at temperatures below 65 °C (150 °F). Its corrosion resistance is enhanced by the presence of oxidizing salts; therefore, it is suitable for use in mixtures containing nitric acid, ferric sulfate, and cupric sulfate. Incoloy 800 is only useful at low concentrations of sulfuric acid at ambient temperatures.

Nickel-base chromium-iron-cobalt-silicon alloys are proprietary alloys developed specifically for hot concentrated sulfuric acid pump and valve applications. Alloy 55 is one such cast alloy. Alloy 66 is a ductile cast alloy that can also be made in the wrought form. Both forms have excellent corrosion resistance in the 0 to 60% and 80 to 90% ranges, but performance is erratic in the 60 to 80% range.

Nickel-base chromium-molybdenum-copper alloys are proprietary alloys designed to resist sulfuric acid concentrations up to 98% at temperatures up to 100 °C (212 °F). Illium 98 is a weldable, machinable cast alloy.

Niobium. Niobium is resistant to sulfuric acid under oxidizing conditions, for example, in concentrated sulfuric acid containing cupric or ferric ions. Niobium is also resistant at room temperature to all concentrations of sulfuric acid up to 95%.

Gold. Gold exhibits excellent resistance to sulfuric acid up to 250 °C (480 °F) and is used when no corrosion or contamination can be tolerated.

Silver. Silver is rapidly attacked by hot concentrated (60%) sulfuric acid and by 95% sulfuric acid at room temperature.

Platinum. Platinum resists sulfuric acid in all concentrations and temperatures.

Palladium. Palladium is generally resistant to corrosion by most single acids, but when air is present, hot sulfuric acid attacks palladium.

Osmium. Osmium is resistant to sulfuric acid.

Rhodium. In wrought or cast form, rhodium is attacked slowly at 100 °C (212 °F) by concentrated sulfuric acid.

Stainless Steels. The conventional austenitic grades exhibit good resistance in very dilute or highly concentrated sulfuric acid at slightly elevated temperatures. Acid in the intermediate concentration is more aggressive; thus conventional grades have very limited use. Aeration or the addition of an oxidizing species stabilizes the chromium-rich passive oxide film that protects the stainless steel and reduces the corrosive action of sulfuric acid. Cations that are easily reduced, such as ferric, cupric, and stannic ions, are oxidizing agents that can inhibit corrosion. Nitric acid concentrations as low as 1.5% were found to inhibit the corrosion of stainless steel over a wide range of concentrations at ambient and elevated temperatures. Concentrated sulfuric acid (above 97%) and oleum are strongly oxidizing and corrosion is reduced dramatically. Most stainless steels and nickel-based alloys experience similar reductions in corrosion rates with increasing concentration.

The resistance of austenitic stainless steels to sulfuric acid is complex due to the active-passive nature of the alloys. Stable passivity is achieved at ambient temperatures in the very low concentrations, very high concentrations, and in oleum. In the oleum range, stainless steels are free from the concerns about minor concentration variations, and corrosion resistance is extended well in excess of 100 °C (212 °F). At ambient temperature, austenitic stainless steels, for example type 304, exhibit passivity in 93% sulfuric acid and are used for piping and tankage where product purity is desirable. Anodic protection by an impressed current can extend the useful temperature and concentration range by holding the stainless steel component in the passive condition. For example, stainless steel may be protected in 93% sulfuric acid up to 70 °C (160 °F) and in 98% sulfuric acid up to 120 °C (250 °F). If a stainless steel is solidly in the passive state, velocity has little effect. However, if the alloy drops to active-passive behavior, usually due to increasing temperature, velocity has a major effect. Abrasive conditions can force active-passive behavior even in 96% sulfuric acid at ambient temperature.

The performance of stainless steel in sulfuric acid depends on the composition of the grade. For example, the presence of nickel and copper in some austenitic grades greatly enhances resistance to sulfuric acid compared to the resistance of ferritic grades. Conventional ferritic grades, such as type 430, have limited use in sulfuric acid. Stainless steels have poor resistance to deaerated dilute solutions. Type 310 stainless steel with 25% chromium and no intentionally added molybdenum is more resistant than the molybdenum-bearing grades when oxidizing agents are present. Type 316 and type 317 are more resistant than any of the other chromium-nickel types of sulfuric acid solutions. They resist solutions up to 5% concentration at temperatures as high as 49 °C (120 °F), and higher concentrations at temperatures under 38 °C (100 °F).

Like the austenitic stainless steels, the corrosion resistance of the higher austenitic stainless steels is also complex. However, the range of passivity and corrosion resistance is extended because of the higher alloy content. Like the stainless steels, active and active-passive behavior are the modes of corrosion. The class of alloys with an iron base and approximately 25% nickel, 20% chromium, and 4.5% molybdenum have higher resistance than type 316 stainless steel as a result of the higher alloy content. Copper, titanium, and niobium are sometimes added as stabilizing agents. The copper-bearing alloys are more resistant than the copper-free alloys over the entire range of sulfuric acid concentrations at ambient temperature.

An alloy that was originally developed for sulfuric acid service, but is used for many other environments, is generally known as Alloy 20. Improved resistance to general corrosion and stress-corrosion cracking has been obtained by increasing the nickel and chromium and molybdenum content to type 316 and 317 stainless steels and adding copper. Its counterpart, cast ACI CN-7M, has equivalent resistance to sulfuric acid and is suitable up to 80 °C (175 °F) at concentrations up to 50%. For higher concentrations, good corrosion resistance is expected up to 65 °C (150 °F). This alloy is fully austenitic and must be solution annealed for maximum corrosion resistance. Although foundries have their own trade names, the alloy is always identified with the number 20, for example, Carpenter 20 (wrought form), FA-20 (austenitic and ductile), Durimet 20, Esco 20, CH-20, and CK-20. This alloy is suitable in all concentrations, with the largest corrosion rates occurring at 78%. The oxidizing agents ferric sulfate and copper sulfate added to the acid act as inhibitors and decrease attack. Alloy 20 is used in contact-process acid plants for pumps and valves. An improved version of the alloy is known as 20Cb-3. This alloy has higher nickel and is stabilized against chromium carbide precipitation. Alloy 20Cb-3, for instance, is used for valve springs in sulfuric acid service.

Austenitic stainless steels containing 5 to 6% silicon, available in either cast or wrought versions, have interesting corrosion characteristics. Corrosion protection is obtained by the formation of a tenacious silicon-rich film produced on the surface during the initial days of corrosion. These alloys resist corrosion in 99% sulfuric acid up to 120 °C (250 °F) without anodic protection and are used for piping and vessels for hot, concentrated sulfuric acid.

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Cast stainless steels have the same corrosion resistance to sulfuric acid as their wrought equivalents. In general, Alloy 20 castings outperform the other cast stainless steels, except in high concentrations and in oleum service. Because the cast version contain second-phase ferrite for castability, proper heat treatment must be undertaken to ensure maximum corrosion resistance. The alloy CD-4MCu, which does not have a wrought counterpart, resists sulfuric acid in all concentrations at ambient temperature and is suitable for oleum service at temperatures above 100 °C (212 °F). The CE-30 cast alloy is resistant to sulfurous acid, sulfites, and mixtures of sulfurous and sulfuric acids. The high-chromium CC-50 cast alloy is used as castings in contact with acid mine waters, sulfuric and nitric acid mixtures, alkaline liquors, and sulfurous liquors.

Corrosion studies of sintered austenitic stainless steels have shown that the corrosion resistance improves with increasing density in dilute sulfuric acid. Stainless steel parts made by extrusion from rapidly solidified powders have superior oxidation resistance, no surface pitting, low pit density within the material, and the lowest corrosion rate at the corrosion potential in 1*M* sulfuric acid. This superior oxidation and corrosion resistance is attributed to the elevated temperature grain growth inhibiting effect of uniformly dispersed manganese sulfide particles.

Tantalum. Tantalum is highly resistant to corrosion by sulfuric acid in all concentrations up to about 98%. It is inert to dilute acid even at boiling temperatures and is not attacked by concentrated acids at temperatures below 150 °C (300 °F). A slow, uniform attack by concentrated sulfuric acid begins on tantalum at about 175 °C (345 °F). However, the corrosion by hot, concentrated sulfuric acid is uniform, and at a temperature as high as 200 °C (390 °F), tantalum can be successfully used with 98% sulfuric acid.

Fuming sulfuric acid (oleum) attacks the metal much more rapidly than the concentrated acid, but the attack is uniform over the entire surface. The presence of impurities does not increase the corrosion rate. Although no failures due to hydrogen embrittlement have been reported for tantalum chemical-processing equipment used in sulfuric acid service, hydrogen embrittlement in tantalum has been produced under special laboratory test conditions.

In applications where a material harder and stronger than the pure metal is desired, Ta-10W binary solid-solution alloy, also known as Fansteel 60 Metal, has been used. For example, Ta-10W alloy is used as an insert in the plug of a tantalum-lined split-body valve to give a hard plug to a soft seat and also to repair glass-lined steel equipment. Tests run at 205 and 230 °C (400 and 450 °F) indicate that either unalloyed tantalum or Ta-10W can be used at 230 °C (450 °F) to handle sulfuric acid in concentrations below 90%. However, the corrosion weight loss of Ta-10W is about twice that of unalloyed tantalum at 230 °C (450 °F) in sulfuric acid over the concentration range of 70 to 90%.

Corrosion tests run in both hot and cold concentrated sulfuric acid on alloys with various proportions of tantalum and niobium showed the corrosion rates increased roughly in proportion to the niobium content of the alloys. Even though the 95Ta-5Nb alloy showed excellent resistance in all exposures, the attack was three times that obtained on pure tantalum. Tests on the materials were carried out in 75% sulfuric acid at 185 °C (360 °F), in 70% at 165 °C (330 °F), and in 75% at room temperature. The tantalum-niobium alloys containing approximately 60% or more tantalum appeared promising for boiling 70% sulfuric acid. The addition of zirconium, hafnium, chromium, and vanadium lowered the corrosion resistance.

Alloy WC-640 was developed for corrosion-resistant applications. It exhibited excellent resistance to all test environments except concentrated sulfuric acid at 200 °C (390 °F). The chemical composition of the alloy corresponded to a ternary tantalum-niobium-tungsten alloy, Ta-40Nb-0.5W, and its tensile strength was similar to that of Tantaloy 63.

Tin. The corrosion rate of tin in sulfuric acid varies with concentration and temperature. At ordinary temperatures, concentrated sulfuric acid has slight action on tin, but as the temperature is increased sulfur dioxide and a little hydrogen sulfide are evolved along with a separation of sulfur. In a more dilute acid (1:3), the reaction occurs at a lower temperature, with more hydrogen sulfide and less sulfur dioxide being formed. In a diluted (1:5) acid, no reaction occurs at 25 °C (75 °F), but at 100 °C (212 °F), hydrogen with a trace of hydrogen sulfide is evolved.

Titanium. Unalloyed titanium is rapidly attacked by all concentrations of sulfuric acid except very dilute solutions at low temperatures. Impurities in the form of oxidizing agents may act as inhibitors; for example, titanium resists 0 to 50% concentrations of sulfuric acid saturated with chlorine. Titanium has also been used in the sulfuric acid leaching of nickel ores, for example, the leaching of a nickel-cobalt ore by a 10% sulfuric acid solution at 246 °C (475 °F). The acid contained 32 to 35% solids that added abrasion to the corrosive environment. Resistance is attributed to the presence of heavy-metal oxidizing agents, such as ferric, cupric, and chromate ions.

Another method of reducing the attack of titanium by sulfuric acid is to use an anodic passivation technique. This consists of coupling the titanium to the positive pole of a DC source and applying a potential of between 1.5 and 12 V. This reinforces the oxide film, which allows the material to withstand attack by 60% sulfuric acid at temperatures up to 90 °C (208 °F). Titanium has been used for electrolyte refining in copper sulfate solutions and for steam coils in 25 to 30% sulfuric acid in pigment processes.

The titanium-palladium alloy, Titanium 260, is significantly more resistant than unalloyed titanium in pure sulfuric acid solutions and is suitable for use in a 4% solution at the boiling point, 10% at 70 °C (158 °F), and 25% at room temperature. After slight initial corrosion, the palladium redeposits on the surface to provide efficient cathodic areas for passivating the anode reaction. The palladium alloys were developed to eliminate crevice and deposit corrosion problems.

Moderate additions of molybdenum to titanium can provide excellent resistance to strong reducing acid environments. The grade 12 alloy, Ti-0.8Ni-0.3Mo, has better resistance to dilute reducing acid solutions than unalloyed titanium and is a less expensive alternative to palladium alloys in services where crevice or deposit attack is a concern. Molybdenum is more efficient than tantalum, niobium, or zirconium in this role.

Hafnium. Hafnium is soluble in concentrated sulfuric acid. It is resistant to dilute sulfuric acid.

Zirconium. Zirconium has excellent resistance to sulfuric acid up to 50% concentration at temperatures to boiling and above. The corrosion resistance of zirconium depends on the formation of the passive film, zirconium dioxide, which is highly ordered and corrosion resistant. Electrochemical measurements shown the corrosion potential of zirconium in sulfuric acid to be located solidly in the passive region when it is resisting corrosion. However, as temperature and/or concentration increases, the transpassive potential (breakdown) decreases, and there is less tolerance for oxidizing agents. At high temperatures in concentrations exceeding 50%, sufficient quantities of oxidizing agents, such as ferric, cupric, and nitrate ions, deplete the passive region, causing zirco-

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nium to corrode actively. However, in 20% or less, zirconium can tolerate a great deal of strong oxidizing agents. Consequently, zirconium equipment is often used in steel pickling processes.

Zirconium weld material may corrode preferentially when sulfuric acid concentration is 55% and higher; therefore, zirconium is seldom used in the welded condition unless it has been heat treated to maximize corrosion resistance. Zirconium finds use in the concentration range of 0 to 50% and in dilute sulfuric acid at elevated temperatures. In these two regions, iron- and nickel-base alloys corrode rapidly, or their resistance depends strongly on concentration, temperature, or aeration. Another important application for zirconium is in processes that cycle between sulfuric acid and alkaline solutions. One company replaced a lead- and brick-lined carbon steel reactor vessel with zirconium because the reaction alternated between hot sulfuric acid and caustic. The vessel has been in use for several years with no corrosion problems.

Zirconium is used in sulfuric acid recovery and recycle systems in which fluorides are not present and the acid concentration does not exceed 65%. Zirconium can tolerate only very small amounts of fluoride ions in sulfuric acid even at low acid concentrations. When heavy-metal ions and halide ions coexist in sulfuric acid (for example, when ferric chloride is present), the optimum acid concentration range for zirconium is 60 to 65%.

The earliest application for zirconium was in the production of hydrogen peroxide using sulfuric acid. Zirconium shell and tube heat exchangers replaced graphite exchangers at one plant where they were used to condense a 75% concentrated sulfuric acid medium. The average maintenance-free life of the heat exchanger was 12 years. The tubes were thinned at the liquid/gas interface area because of bubble collapse, but no other corrosion occurred. Because of this experience, the company used zirconium shell and tube exchangers in the manufacture of acrylic films and fibers. In this application, the sulfuric acid concentration was as high as 60% at 150 °C (300 °F). Acid concentration limit is very important when zirconium is used to handle sulfuric acid at elevated temperatures in the marginal concentration region, such as 60% or more. When the limit is exceeded, zirconium may corrode rapidly. Acid concentration may change significantly because of an imperfect seal, or when the system is under vacuum because the water vapor is continuously taken away.

Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	20 (68)	...	Questionable	...	92
Carbon and alloy steels									
16Ni, 8Cr, 5Si, 1Cu	...	...	...	IN	50	102 h	0.37 (14.6)	...	206
16Ni, 8Cr, 5Si, 1Cu, 1Mo	...	...	...	IN	50	102 h	0.83 (33.0)	...	206
ASTM A106 carbon steel	G10100	...	1.5*N*	...	45 (115)	3 h	20 (787)	...	31
ASTM A106 carbon steel	G10100	.	Dilute, 1.5*N*	...	45 (115)	3 h	20 (787)	...	31
ASTM A335, grade P11 (1.5Cr-0.25Mo)	K11597	...	1.5*N*	...	45 (115)	3 h	41 (1600)	...	31
ASTM A335, grade P22 (2Cr-1Mo)	K21590	...	1.5*N*	...	45 (115)	3 h	330 (13000)	...	31
ASTM A335, grade P5 (5Cr-0.5Mo)	K51545	...	1.5*N*	...	45 (115)	3 h	94 (3700)	...	31
ASTM A335, grade P9 (10Cr-1Mo)	S50400	...	1.5*N*	...	45 (115)	3 h	83 (3270)	...	31
Copper and alloys									
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	To 50	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	Pressure of 13.3 kPa (100 torr)	30	Boiling	48 h	...	...	54
Cartridge brass	C26000	...	Pressure of 13.3 kPa (100 torr)	40	Boiling	48 h	...	...	54
Cartridge brass	C26000	...	Pressure of 13.3 kPa (100 torr)	50	Boiling	48 h	...	...	54
Cartridge brass	C26000	...	Pressure of 13.3 kPa (100 torr)	60	Boiling	48 h	...	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	30	Boiling	48 h	0.70 (27) max	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	40	Boiling	48 h	0.7 (28) max	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	50	Boiling	48 h	0.8 (31) max	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	60	Boiling	48 h	2.3 (89) max	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	70	Boiling	48 h	1.1 (42) max	...	54
Electrolytic copper	C11000	...	Pressure of 13.3 kPa (100 torr)	80	Boiling	48 h	166 (6550) max	...	54

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Electrolytic copper	C11000	...	Solution agitated	30	...	24 h	0.25 (9.6) max	...	54
Electrolytic copper	C11000	...	Solution agitated	40	...	24 h	0.6 (2.4) max	...	54
Electrolytic copper	C11000	...	Solution agitated	50	...	24 h	0.06 (2.4)	...	54
Electrolytic copper	C11000	...	Solution agitated	60	...	24 h	0.09 (3.6) max	...	54
Electrolytic copper	C11000	...	Solution agitated	70	...	24 h	2.7 (108) max	...	54
Electrolytic copper	C11000	...	Solution agitated	80	...	24 h	39 (1610) max	...	54
Muntz metal	C28000	...	Pressure of 13.3 kPa (100 torr)	80	Boiling	48 h	206 (8100) max	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	30	Boiling	48 h	0.6 (25)	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	40	Boiling	48 h	0.5 (18) max	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	50	Boiling	48 h	0.9 (36)	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	60	Boiling	48 h	3.4 (133) max	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	70	Boiling	48 h	1.1 (42) max	...	54
Phosphor bronze, 5% Sn	C51000	...	Pressure of 13.3 kPa (100 torr)	80	Boiling	48 h	62 (2440) max	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	30	Boiling	48 h	0.7 (26) max	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	40	Boiling	48 h	0.5 (22) max	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	50	Boiling	48 h	0.6 (24)	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	60	Boiling	48 h	2.4 (94) max	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	70	Boiling	48 h	0.9 (37) max	...	54
Phosphor deoxidized copper	C14200	...	Pressure of 13.3 kPa (100 torr)	80	Boiling	48 h	527 (21000) max	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	30	...	24 h	0.34 (13) max	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	40	...	24 h	Resistant	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	50	...	24 h	0.06 (2.4) max	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	60	...	24 h	0.06 (2.4) max	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	70	...	24 h	2.1 (84) max	...	54
Phosphor deoxidized copper	C14200	...	Solution agitated	80	...	24 h	51 (1990) max	...	54
Yellow brass	C27000	...	Pressure of 13.3 kPa (100 torr)	70	Boiling	48 h	0.7 (31) max	...	54
Iron and alloys									
Armco iron	...	...	1.5*N*	...	45 (115)	3 h	22 (866)	...	31
Armco iron	...	...	Dilute, 1.5*N*	...	45 (115)	3 h	22 (866)	...	31
Miscellaneous									
85WC-15Co	...	...	...	10	22 (72)	48 h	0.6 (25)	...	34
85WC-15Co	...	...	...	10	22 (72)	48 h	0.3 (12)	...	34
94WC-6Co	...	...	...	10	22 (72)	48 h	0.1 (3)	...	34
94WC-6Ni	...	...	...	10	22 (72)	48 h	0.02 (0.9)	...	34
Chemical lead	L51120	...	...	54	118 (245)	...	.19 (7.4)	...	254
Chemical lead	L51120	...	...	78	24 (75)	...	.03 (1)	...	
Chemical lead	L51120	...	...	78	50 (122)	...	.05 (2)	...	
Chemical lead	L51120	...	With 1% nitric acid	54	118 (245)	...	.15 (5.9)	...	254
Chemical lead	L51120	...	With 1% nitric acid	78	24 (75)	...	.08 (3)	...	
Chemical lead	L51120	...	With 1% nitric acid	78	50 (122)	...	0.3 (12)	...	254
Chemical lead	L51120	...	With 3.5% nitric acid	78	24 (75)	...	.09 (3.6)	...	254
Chemical lead	L51120	...	With 3.5% nitric acid	78	50 (122)	...	.45 (18)	...	254
Chemical lead	L51120	...	With 5% nitric acid	54	118 (245)	...	.22 (8.4)	...	254
Chemical lead	L51120	...	With 7.5% nitric acid	78	24 (75)	...	0.1 (4)	...	254
Chemical lead	L51120	...	With 7.5% nitric acid	78	50 (122)	...	.88 (35)	...	254
Gold	P00016	...	...	All	250 (480)	...	0.05 (2) max	...	8
High purity lead	L50001	...	...	...	60 (140)	...	0.3 (12)	...	254
High purity lead	L50001	...	...	...	80 (176)	...	0.9 (36)	...	254
High purity lead	L50001	...	With 6.7% sodium chloride	33	24 (75)	...	0.15 (6)	...	254
Iridium	...	...	...	Concentrated	Room to 100 (212)	...	Resistant	...	29
Lead	L50045	...	Evaporator. Concentrated bath plus 30% Na_2SO_4	20	55 (130)	...	0.1 (4)	...	48

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Lead	L50045	...	Evaporator. Plus 17% Na_2SO_4, 30% other inorganic sulfates	6	40 (104)	...	0.1 (5)	...	48
Lead	L50045	...	Plus 6.7% NaCl	33	24 (75)	...	0.2 (6)	...	49
Lead	L50045	...	Plus 6.7% NaCl	33	60 (140)	...	0.3 (12)	...	49
Lead	L50045	...	Plus 6.7% NaCl	33	80 (176)	...	0.9 (36)	...	49
Lead, 6% anitmonial	L53110	...	...	54	118 (245)	...	.35 (14)	...	254
Lead, 6% anitmonial	L53110	...	With 1% nitric acid	54	118 (245)	...	.55 (22)	...	254
Lead, 6% anitmonial	L53110	...	With 5% nitric acid	54	118 (245)	...	2.9 (114)	...	254
Magnesium	...	...	...	All	Room	...	Poor	...	119
Osmium	...	...	...	Concentrated	100 (212)	...	Resistant	...	17
Palladium	P03980	...	...	Concentrated	Room	...	0.3 (10) max	...	17
Palladium	P03980	...	...	Concentrated	100 (212)	...	1.6 (63)	...	17
Rhodium	P05990	...	...	Concentrated	100 (212)	...	0.25 (10) max	...	29
Ruthenium	...	...	...	95	100 (212)	...	Resistant	...	18
Silver	P07010	...	...	10	Boiling	...	0.003 (0.1)	...	4
Silver	P07010	...	...	10	Boiling	...	0.003 (0.1)	...	4
Silver	P07010	...	...	50	Boiling	...	0.03 (1.3)	...	4
Silver	P07010	...	...	50	Boiling	...	0.03 (1.3)	...	4
Silver	P07010	...	...	60	Boiling	...	0.9 (35)	...	4
Silver	P07010	...	...	60	Boiling	...	0.9 (35)	...	4
Silver	P07010	...	...	95	Room	...	0.1 (6)	...	4
Silver	P07010	...	...	95	Room	...	0.1 (6)	...	4
Tin	...	...	...	50 max	20 (68)	...	Poor	...	94
Tin	...	...	...	50 max	60 (140)	...	Poor	...	94
Tin	...	...	...	50 max	100 (212)	...	Poor	...	94
Tin	...	...	...	70	20 (68)	...	Poor	...	94
Tin	...	...	...	70	60 (140)	...	Poor	...	94
Tin	...	...	...	70	100 (212)	...	Poor	...	94
Tin	...	...	...	95	20 (68)	...	Poor	...	94
Tin	...	...	...	95	60 (140)	...	Poor	...	94
Tin	...	...	...	95	100 (212)	...	Poor	...	94
Tin	...	...	Fuming	...	20 (68)	...	Poor	...	94
Tin	...	...	Fuming	...	60 (140)	...	Poor	...	94
Tin	...	...	Fuming	...	100 (212)	...	Poor	...	94
Tin	...	...	Hydrogen	6	...	...	0.2 (7)	...	59
Tin	...	...	Oxygen	6	...	...	22 (860)	...	59
Nickel and alloys									
Alloy 625	N06625	...	...	50	79 (174)	...	1.3 (52)	...	63
Alloy 625	N06625	...	...	10	Boiling	...	1.2 (46)	...	63
Alloy 625	N06625	...	...	20	66 (150)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	20	79 (174)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	20	Boiling	...	3 (124)	...	63
Alloy 625	N06625	...	...	30	66 (150)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	30	79 (174)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	30	Boiling	...	6 (238)	...	63
Alloy 625	N06625	...	...	40	38 (100)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	40	66 (150)	...	0.4 (17)	...	63
Alloy 625	N06625	...	...	40	79 (174)	...	0.9 (35)	...	63
Alloy 625	N06625	...	...	50	38 (100)	...	0.03 (1)	...	63
Alloy 625	N06625	...	...	50	66 (150)	...	0.6 (25)	...	63
Alloy 625	N06625	...	...	60	38 (100)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	70	38 (100)	...	0.03 (1) max	...	63
Alloy 625	N06625	...	...	80	38 (100)	...	0.03 (1) max	...	63

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 625	N06625	...	...	10	Boiling	...	0.93 (37)	...	212
Alloy 625	N06625	...	...	60	Boiling	...	2.63 (105)	...	212
Alloy 625	N06625	...	...	56	Boiling	...	0.58 (23)	...	212
Alloy 625	N06625	...	...	10	Boiling	...	.93 (37)	...	222
Alloy 625	N06625	...	...	10	Boiling	...	1.15 (46)	...	225
Alloy 625	N06625	...	...	10	70 (158)	...	3.03 (121)	...	225
Alloy 625	N06625	...	Dilute. Activated before tests	1	Boiling	...	0.06 (2)	...	98
Alloy 625	N06625	...	Dilute. Activated before tests	5	Boiling	...	0.2 (9)	...	98
Alloy 625	N06625	...	Dilute. Activated before tests	10	Boiling	...	0.6 (25)	...	98
Alloy 625	N06625	...	Plus 0.1% HCl	5	Boiling	...	4 (151)	...	63
Alloy 625	N06625	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	0.03 (1.0)	...	224
Alloy 625	N06625	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	0.045 (1.8)	...	224
Alloy 625	N06625	...	Plus 0.5% HCl	5	Boiling	...	11 (434)	...	63
Alloy 625	N06625	...	Plus 1% HCl	10	70 (158)	...	3 (121)	...	63
Alloy 625	N06625	...	Plus 1% HCl	10	90 (194)	...	8 (326)	...	63
Alloy 625	N06625	...	Plus 1% HCl	10	Boiling	...	22 (869)	...	63
Alloy 625	N06625	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$	11.5	Boiling	...	42 (1664)	...	63
Alloy 625	N06625	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$ (ASTM G28B)	23	Boiling	...	98 (3850)	...	63
Alloy 625	N06625	...	Plus 1.2% HCl, 1% $FeCl_3$, 1% $CuCl_2$	23	Boiling	...	96 (3847)	...	225
Alloy 625	N06625	...	Plus 2% HF	10	Boiling	...	1.4 (55)	...	63
Alloy 625	N06625	...	Plus 200 ppm Cl^-	25	70 (158)	...	1.8 (110)	...	63
Alloy 625	N06625	...	Plus 200 ppm Cl^-	25	Boiling	...	8 (325)	...	63
Alloy 625	N06625	...	Plus 21.5% HNO_3	38.5	Boiling	...	0.60 (24)	...	225
Alloy 625	N06625	...	Plus 26.3% HNO_3	47.1	Boiling	...	0.90 (36)	...	225
Alloy 625	N06625	...	Plus 41.9% HNO_3	24.9	Boiling	...	0.48 (19)	...	225
Alloy 625	N06625	...	Plus 42 g/L $Fe_2(SO_4)_3$ (ASTM G28A)	50	Boiling	...	0.6 (23)	...	63
Alloy 625	N06625	...	Plus 55.9% HNO_3	12.5	Boiling	...	0.50 (20)	...	225
Alloy 690	N06690	...	...	20	Room	7 d	0.05 (2)	...	57
Alloy 690	N06690	...	...	40	Room	7 d	0.03 (1) max	...	57
Alloy 690	N06690	...	...	60	Room	7 d	0.05 (2)	...	57
Alloy 690	N06690	...	...	80	Room	7 d	0.03 (1) max	...	57
Alloy 690	N06690	...	...	98	Room	7 d	0.5 (20)	...	57
Alloy 825	N08825	...	...	10	Boiling	...	0.50 (20)	...	212
Alloy 825	N08825	...	...	60	Boiling	...	2.13 (85)	...	212
Alloy 825	N08825	...	...	56	Boiling	...	0.28 (11)	...	212
Alloy 825	N08825	...	Activated	...	Boiling	...	.060 (2.2)	...	223
Alloy 825	N08825	...	Activated	...	Boiling	...	0.23 (8.9)	...	223
Alloy 825	N08825	...	Metal pickling	10	48-71 (120-160)	23 d	0.3 (13)	...	89
Alloy 825	N08825	...	Not activated	...	Boiling	...	.070 (2.8)	...	223
Alloy 825	N08825	...	Not activated	...	Boiling	...	0.32 (12.7)	...	223
Alloy B-2	N10665	...	...	99	130 (266)	96 h	0.22 (8.5)	...	224
Alloy B-2	N10665	...	...	96	130 (266)	...	0.17 (6.6)	...	224
Alloy B-2	N10665	...	Plus 0.45% HCl	1.8	175 (347)	...	0.16 (6.5)	...	225
Alloy B-2	N10665	...	Plus 0.45% HCl	3.5	175 (347)	...	.16 (6.2)	...	225
Alloy B-2	N10665	...	Plus 0.45% HCl	6.8	175 (347)	...	.15 (6.0)	...	225
Alloy B-2	N10665	...	Plus 1.3% HCl	5.0	175 (347)	...	.18 (7.1)	...	225
Alloy B-2	N10665	...	Plus 1.7% HCl	1.8	175 (347)	...	0.19 (7.7)	...	225
Alloy B-2	N10665	...	Plus 10 ppm nitrate	96	130 (266)	...	0.58 (23)	...	224
Alloy B-2	N10665	...	Plus 1000 ppm ferric ion	96	130 (266)	...	0.25 (9.8)	...	224
Alloy B-2	N10665	...	Plus 1000 ppm nitrate	96	130 (266)	...	3.7 (148)	...	224

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy C-22	N06022	...	...	10	Boiling	...	0.3 (11)	...	63
Alloy C-22	N06022	...	...	20	66 (150)	...	0.0254 (1) max	...	63
Alloy C-22	N06022	...	...	20	79 (174)	...	0.02 (1)	...	63
Alloy C-22	N06022	...	...	20	Boiling	...	0.8 (33)	...	63
Alloy C-22	N06022	...	...	30	66 (150)	...	0.03 (1)	...	63
Alloy C-22	N06022	...	...	30	79 (174)	...	0.08 (3)	...	63
Alloy C-22	N06022	...	...	30	Boiling	...	1.6 (64)	...	63
Alloy C-22	N06022	...	...	40	38 (100)	...	0.03 (1) max	...	63
Alloy C-22	N06022	...	...	40	66 (150)	...	0.03 (1) max	...	63
Alloy C-22	N06022	...	...	40	79 (174)	...	0.2 (6)	...	63
Alloy C-22	N06022	...	...	50	38 (100)	...	0.03 (1) max	...	63
Alloy C-22	N06022	...	...	50	66 (150)	...	0.03 (1)	...	63
Alloy C-22	N06022	...	...	50	79 (174)	...	0.4 (16)	...	63
Alloy C-22	N06022	...	...	60	38 (100)	...	0.0254 (1) max	...	63
Alloy C-22	N06022	...	...	70	38 (100)	...	Resistant	...	63
Alloy C-22	N06022	...	...	80	38 (100)	...	Resistant	...	63
Alloy C-22	N06022	...	...	10	Boiling	...	0.28 (11)	...	225
Alloy C-22	N06022	...	...	10	70 (158)	...	.013 (0.5)	...	225
Alloy C-22	N06022	...	Plus 0.1% HCl	5	Boiling	...	0.07 (26)	...	63
Alloy C-22	N06022	...	Plus 0.45% HCl	1.8	175 (347)	...	.003 (0.1)	...	225
Alloy C-22	N06022	...	Plus 0.45% HCl	3.5	175 (347)	...	.008 (0.3)	...	225
Alloy C-22	N06022	...	Plus 0.45% HCl	6.8	175 (347)	...	.023 (0.9)	...	225
Alloy C-22	N06022	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	0.04 (1.6)	...	224
Alloy C-22	N06022	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	0.08 (3.0)	...	224
Alloy C-22	N06022	...	Plus 0.5% HCl	5	Boiling	...	2 (61)	...	63
Alloy C-22	N06022	...	Plus 1% HCl	10	70 (158)	...	0.0254 (1) max	...	63
Alloy C-22	N06022	...	Plus 1% HCl	10	90 (194)	...	2 (93)	...	63
Alloy C-22	N06022	...	Plus 1% HCl	10	Boiling	...	6 (225)	...	63
Alloy C-22	N06022	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$	11.5	Boiling	...	0.08 (3)	...	63
Alloy C-22	N06022	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$ (ASTM G28B)	23	Boiling	...	0.2 (7)	...	63
Alloy C-22	N06022	...	Plus 1.2% HCl, 1% $FeCl_3$, 1% $CuCl_2$	23	Boiling	...	0.18 (7)	...	225
Alloy C-22	N06022	...	Plus 1.3% HCl	5.0	175 (347)	...	.03 (1.2)	...	225
Alloy C-22	N06022	...	Plus 1.7% HCl	1.8	175 (347)	...	.018 (0.7)	...	225
Alloy C-22	N06022	...	Plus 2% HCl	10	Boiling	...	0.7 (29)	...	63
Alloy C-22	N06022	...	Plus 200 ppm Cl^-	25	70 (158)	...	0.3 (11)	...	63
Alloy C-22	N06022	...	Plus 200 ppm Cl^-	25	Boiling	...	6 (226)	...	63
Alloy C-22	N06022	...	Plus 21.5% HNO_3	38.5	Boiling	...	2.35 (94)	...	225
Alloy C-22	N06022	...	Plus 26.3% HNO_3	47.1	Boiling	...	2.28 (91)	...	225
Alloy C-22	N06022	...	Plus 41.9% HNO_3	24.9	Boiling	...	2.00 (80)	...	225
Alloy C-22	N06022	...	Plus 42 g/L $Fe_2(SO_4)_3$ (ASTM G28A)	50	Boiling	...	0.6 (24)	...	63
Alloy C-22	N06022	...	Plus 55.9% HNO_3	12.5	Boiling	...	1.55 (62)	...	225
Alloy C-276	N10276	...	...	60	50 (122)	...	0.1 (5)	...	120
Alloy C-276	N10276	...	...	10	79 (175)	...	0.13 (5)	...	222
Alloy C-276	N10276	...	...	10	Boiling	...	0.38 (15)	...	222
Alloy C-276	N10276	...	...	99	130 (266)	96 h	1.25 (50)	...	224
Alloy C-276	N10276	...	...	10	Boiling	...	0.58 (23)	...	225
Alloy C-276	N10276	...	...	10	70 (158)	...	0.28 (11)	...	225
Alloy C-276	N10276	...	Plus 0.45% HCl	1.8	175 (347)	...	.03 (1.2)	...	225
Alloy C-276	N10276	...	Plus 0.45% HCl	3.5	175 (347)	...	.05 (2)	...	225
Alloy C-276	N10276	...	Plus 0.45% HCl	6.8	175 (347)	...	.35 (14)	...	225

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy C-276	N10276	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	0.50 (20)	...	224
Alloy C-276	N10276	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	0.80 (32)	...	224
Alloy C-276	N10276	...	Plus 1.2% HCl, 1% $FeCl_3$, 1% $CuCl_2$	23	Boiling	...	1.37 (55)	...	225
Alloy C-276	N10276	...	Plus 1.3% HCl	5.0	175 (347)	...	.63 (25)	...	225
Alloy C-276	N10276	...	Plus 1.7% HCl	1.8	175 (347)	...	.33 (13)	...	225
Alloy C-276	N10276	...	Plus 21.5% HNO_3	38.5	Boiling	...	17.2 (687)	...	225
Alloy C-276	N10276	...	Plus 26.3% HNO_3	47.1	Boiling	...	12.6 (503)	...	225
Alloy C-276	N10276	...	Plus 41.9% HNO_3	24.9	Boiling	...	15.8 (630)	...	225
Alloy C-276	N10276	...	Plus 55.9% HNO_3	12.5	Boiling	...	12.5 (498)	...	225
Alloy C-4	N06455	...	...	10	Boiling	...	0.8 (31)	...	63
Alloy C-4	N06455	...	...	20	66 (150)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	20	79 (174)	...	0.05 (2)	...	63
Alloy C-4	N06455	...	...	20	Boiling	...	0.9 (36)	...	63
Alloy C-4	N06455	...	...	30	66 (150)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	30	79 (174)	...	0.08 (3)	...	63
Alloy C-4	N06455	...	...	30	Boiling	...	1.9 (73)	...	63
Alloy C-4	N06455	...	...	40	38 (100)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	40	66 (150)	...	0.3 (10)	...	63
Alloy C-4	N06455	...	...	40	79 (174)	...	0.4 (15)	...	63
Alloy C-4	N06455	...	...	50	38 (100)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	50	66 (150)	...	0.3 (13)	...	63
Alloy C-4	N06455	...	...	50	79 (174)	...	0.6 (25)	...	63
Alloy C-4	N06455	...	...	60	38 (100)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	70	38 (100)	...	0.05 (2)	...	63
Alloy C-4	N06455	...	...	80	38 (100)	...	0.03 (1) max	...	63
Alloy C-4	N06455	...	...	10	Boiling	...	0.78 (31)	...	225
Alloy C-4	N06455	...	...	10	70 (158)	...	0.6 (24)	...	225
Alloy C-4	N06455	...	Plus 0.1% HCl	5	Boiling	...	1.2 (49)	...	63
Alloy C-4	N06455	...	Plus 0.5% HCl	5	Boiling	...	2.3 (91)	...	63
Alloy C-4	N06455	...	Plus 1% HCl	10	70 (158)	...	0.6 (24)	...	63
Alloy C-4	N06455	...	Plus 1% HCl	10	90 (194)	...	1.7 (66)	...	63
Alloy C-4	N06455	...	Plus 1% HCl	10	Boiling	...	4.9 (192)	...	63
Alloy C-4	N06455	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$	11.5	Boiling	...	26 (1020)	...	63
Alloy C-4	N06455	...	Plus 1.2% HCl plus 1% $FeCl_3$ plus 1% $CuCl_2$ (ASTM G28B)	23	Boiling	...	58 (2294)	...	63
Alloy C-4	N06455	...	Plus 1.2% HCl, 1% $FeCl_3$, 1% $CuCl_2$	23	Boiling	...	57 (229 4)	...	225
Alloy C-4	N06455	...	Plus 2% HF	10	Boiling	...	0.7 (26)	...	63
Alloy C-4	N06455	...	Plus 200 ppm Cl^-	25	70 (158)	...	0.9 (37)	...	63
Alloy C-4	N06455	...	Plus 200 ppm Cl^-	25	Boiling	...	5 (182)	...	63
Alloy C-4	N06455	...	Plus 42 g/L $Fe_2(SO_4)_3$ (ASTM G28A)	50	Boiling	...	4 (167)	...	63
Alloy G	N06007	...	...	98	110 (230)	...	0.73 (29)	...	225
Alloy G	N06007	...	...	10	Boiling	...	0.60 (24)	...	225
Alloy G-3	N06985	...	...	98	110 (230)	...	0.73 (29)	...	212
Alloy G-3	N06985	...	...	99	130 (266)	96 h	1.83 (73)	...	224
Alloy G-3	N06985	...	Plus 0.45% HCl	1.8	175 (347)	...	.008 (0.3)	...	225
Alloy G-3	N06985	...	Plus 0.45% HCl	3.5	175 (347)	...	.48 (19)	...	225
Alloy G-3	N06985	...	Plus 0.45% HCl	6.8	175 (347)	...	.23 (9)	...	225
Alloy G-3	N06985	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	1.88 (75)	...	224
Alloy G-3	N06985	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	0.02 (0.8)	...	224
Alloy G-3	N06985	...	Plus 1.3% HCl	5.0	175 (347)	...	0.9 (36)	...	225

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy G-3	N06985	...	Plus 1.7% HCl	1.8	175 (347)	...	1.78 (71)	...	225
Alloy G-3	N06985	...	Plus 21.5% HNO_3	38.5	Boiling	...	0.48 (19)	...	225
Alloy G-3	N06985	...	Plus 26.3% HNO_3	47.1	Boiling	...	0.68 (27)	...	225
Alloy G-3	N06985	...	Plus 41.9% HNO_3	24.9	Boiling	...	0.48 (19)	...	225
Alloy G-3	N06985	...	Plus 55.9% HNO_3	12.5	Boiling	...	0.40 (16)	...	225
Alloy G-30	N06030	...	...	98	110 (230)	...	0.43 (17)	...	212
Alloy G-30	N06030	...	...	10	Boiling	...	(31)	...	212
Alloy G-30	N06030	...	...	60	Boiling	...	1.13 (45)	...	212
Alloy G-30	N06030	...	...	56	Boiling	...	0.18 (7)	...	212
Hastelloy B	N10001	...	...	10	93 (200)	672 h	1.3 (50) min	...	68
Hastelloy B	N10001	...	Dicyclopentadiene hydrate reaction. Pilot plant	15	115-130 (238-266)	220 h	0.51 (20) min	...	68
Hastelloy B	N10001	...	Nickel sulfide impuritie	10	107 (225)	240 h	0.25 (10) max	...	68
Hastelloy B	N10001	...	Plus 0-5% Na_2SO_4, 0-0.05% $ZnSO_4$, 0.02% CS_3, trace of H_2S	0-3	93 (200)	...	0.5 (20) min	...	68
Hastelloy B	N10001	...	Plus 0.04% SO_2, and varying amounts of carbon on bottom tray of SO_2 scrubber in regeneration of alkylation acid	0.1	73-81 (164-177)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 0.50-0.56 oz/gal Cu	5	80-85 (175-185)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 0.8-5.3% $AlSO_4$, 0-0.3% $KCr(SO_4)_2$, H_2O, moderate aeration	2.8-9.3	28 (83)	...	0.5 (20) min	...	68
Hastelloy B	N10001	...	Plus 1% HF, 3% Na_2SO_4, 1% $SiO_2.2H_2O_2$, 0.5% Na_2SiF_6, balance water in separation of Na_2SiF_6	9	27-49 (80-120)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 1-2% Cu, 7000 oz/ton Ag. 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu. Traces Ag, Au, Sb, Co	20	52 (125)	90 d	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 10-12% Na_2SO_4.	10-12	349 (660)	...	0.05 (2) max	...	68
Hastelloy B	N10001	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus 20 oz. $Na_2Cr_2O_7$ per 18 ga	5	21-29 (70-85)	...	0.05 (2) max	...	68
Hastelloy B	N10001	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.5 (20) min	...	68
Hastelloy B	N10001	...	Plus 9.6% $FeSO_4$, 12% Ti as sulfate. Maximum pitting, 0.076 mm/yr (3 mils/yr)	24	19-21 (66-70)	...	0.05 (2) max	...	68
Hastelloy B	N10001	...	Plus $CO_2(SO_4)_3$, $FeSO_4$, trace $CuSO_4$	20	15-90 (59-194)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	Plus $FeSO_4$, 0.05% TiO_2 (0.008% solids).	5	32 (90)	...	0.51 (20) min	...	68
Hastelloy B	N10001	...	Plus Na_2SO_4 and glucose in rayon spin bath	10	45 (113)	...	0.05 (2) max	...	68
Hastelloy B	N10001	...	Plus ore containing MnO and MnO_2	5	82 (180)	...	0.5 (20) min	...	68
Hastelloy B	N10001	...	Plus sugar from digestion of tuber barbasco. Process is for obtatining steroid used in hormone production	15	120 (248)	...	0.25 (10) max	...	68
Hastelloy B	N10001	...	Plus sulfate oils, traces of NaCl and Na_2SO_4	5	50 (122)	...	0.25 (10) max	...	68
Hastelloy B	N10001	...	Saturated with $CuSO_4$. Pickling copper and brass. Aeration, moderate agitation	20	60 (140)	120 d	0.25 (10) max	...	68
Hastelloy B	N10001	...	Saturated with NaCl. Maximum pitting, 0.35 mm/yr (14 mils/yr)	2	48-52 (118-126)	...	0.05 (2) max	...	68
Hastelloy B	N10001	...	SO_2 purge	10	38 (100)	...	1.3 (50) min	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy B	N10001	...	SO_2 purge	10	65 (150)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	SO_2 purge	10	93 (200)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	SO_2 purge	10	Boiling	...	0.25 (10) max	...	68
Hastelloy B	N10001	...	Steel pickling tank	8	49-60 (120-140)	...	0.25 (10) max	...	68
Hastelloy B	N10001	...	To 5% (final before discarding), 0.09% (original) to 0.54% (final) $FeSO_4$. Inhibited with Activol 3591	16	74 (165)	...	1.3 (50) min	...	68
Hastelloy B	N10001	...	Zr-HF separation	20	Room	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	...	10	93 (200)	672 h	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	...	10-12	349 (660)	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	Dicyclopentadiene hydrate reaction. Pilot plant	15	115-130 (238-266)	220 h	0.5 (20) min	...	68
Hastelloy B-2	N10665	...	Nickel sulfide impurities	10	107 (225)	240 h	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	Plus 0-5% Na_2SO_4, 0-0.05% $ZnSO_4$, 0.02% CS_3, trace of H_2S	0-3	93 (200)	...	0.5 (20) min	...	68
Hastelloy B-2	N10665	...	Plus 0.04% SO_2, and varying amounts of carbon on bottom tray of SO_2 scrubber in regeneration of alkylation acid	0.1	73-81 (164-177)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 0.50-0.56 oz/gal Cu	5	80-85 (175-185)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 0.8-5.3% $AlSO_4$, 0-0.3% $KCr(SO_4)_2$, H_2O, moderate aeration	2.8-9.3	28 (83)	...	0.5 (20) min	...	68
Hastelloy B-2	N10665	...	Plus 1% HF, 3% Na_2SO_4, 1% $SiO_2.2H_2O_2$, 0.5% Na_2SiF_6, balance water in separation of Na_2SiF_6	9	27-49 (80-120)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 1-2% Cu, 7000 oz/ton Ag, 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu. Traces Ag, Au, Sb, Co	20	52 (125)	90 d	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus 20 oz. $Na_2Cr_2O_7$ per 18 gal	5	21-29 (70-85)	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.51 (20) min	...	68
Hastelloy B-2	N10665	...	Plus 9.6% $FeSO_4$, 12% Ti as sulfate. Maximum pitting, 0.076 mm/yr (3 mils/yr)	24	19-21 (66-70)	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	Plus $CO_2(SO_4)_3$, $FeSO_4$, trace $CuSO_4$	20	15-90 (59-194)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Plus $FeSO_4$, 0.05% TiO_2 (0.008% solids)	5	32 (90)	...	0.5 (20) min	...	68
Hastelloy B-2	N10665	...	Plus Na_2SO_4 and glucose in rayon spin bath	10	45 (113)	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	Plus ore containing MnO and MnO_2	5	82 (180)	...	0.5 (20) min	...	68
Hastelloy B-2	N10665	...	Plus sugar from digestion of tuber barbasco. Process is for obtaining steroid used in hormone production	15	120 (248)	...	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	Plus sulfate oils, traces of NaCl and Na_2SO_4	5	50 (122)	...	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	Saturated with $CuSO_4$. Pickling copper and brass. Aeration, moderate agitation	20	60 (140)	120 d	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	Saturated with NaCl	2	48-52 (118-126)	...	0.05 (2) max	...	68
Hastelloy B-2	N10665	...	SO_2 purge	10	38 (100)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	SO_2 purge	10	65 (150)	...	1.3 (50) min	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy B-2	N10665	...	SO_2 purge	10	93 (200)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	SO_2 purge	10	Boiling	...	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	Steel pickling tank	8	49-60 (120-140)	...	0.25 (10) max	...	68
Hastelloy B-2	N10665	...	To 5% (final before discarding), 0.09% (original) to 0.54% (final) $FeSO_4$. Inhibited with Activol 3591	16	74 (165)	...	1.3 (50) min	...	68
Hastelloy B-2	N10665	...	Zr-HF separation	20	Room	...	0.05 (2) max	...	68
Hastelloy C	...	...	...	10	93 (200)	672 h	0.5 (20) min	...	68
Hastelloy C	...	...	Aeration, lab test	5	58-67 (137-153)	29.5 d	0.05 (2) max	...	68
Hastelloy C	...	...	As scrubbing liquid, moderate aeration	1-23	150 (302)	...	1.3 (50) min	...	68
Hastelloy C	...	...	Dicyclopentadiene hydrate reaction. Pilot plant	15	115-130 (238-266)	220 h	1.3 (50) min	...	68
Hastelloy C	...	...	Hot H_2SO_4, pH 3.0, containing tungsten and molybdenum salts with 2-3 g/L fluorides, moderate aeration	0-4	60 (140)	...	0.05 (2) max	...	68
Hastelloy C	...	...	In pickling stainless foil plus 3% HCl. First pickle is followed by 15 min in 10% cold HNO_3	18	77-82 (170-180)	...	0.03 (1)	...	68
Hastelloy C	...	...	Lab test	10	Boiling	120 h	0.5 (20) min	...	68
Hastelloy C	...	...	Nickel sulfide impurities	10	107 (225)	240 h	1.3 (50) min	...	68
Hastelloy C	...	...	Plus 0-5% Na_2SO_4, 0-0.05% $ZnSO_4$, 0.02% CS_3, trace of H_2S	0-3	93 (200)	...	0.025 (1)	...	68
Hastelloy C	...	...	Plus 0.04% SO_2, and varying amounts of carbon on bottom tray of SO_2 scrubber in regeneration of alkylation acid	0.1	73-81 (164-177)	...	0.05 (2) max	...	68
Hastelloy C	...	...	Plus 0.1% $CuSO_4$ and some alcohols	2.5	93-121 (200-250)	...	0.2 (8.2)	...	68
Hastelloy C	...	...	Plus 0.35 oz/gal $NaNO_3$	6-9	68-79 (155-175)	...	0.9 (34)	...	68
Hastelloy C	...	...	Plus 0.5-3.5% $CuSO_4$ and abrasive anode mud from electrolytic copper refining	20-30	77-82 (170-180)	...	0.38 (15)	...	68
Hastelloy C	...	...	Plus 0.50-0.56 oz/gal Cu	5	80-85 (175-185)	...	0.05 (1.9)	...	68
Hastelloy C	...	...	Plus 0.8-0.9 oz/gal $NaNO_3$ in pickling tank	7-8	68-74 (155-165)	...	0.05 (2.1)	...	68
Hastelloy C	...	...	Plus 0.8-5.3% $AlSO_4$, 0-0.3% $KCr(SO_4)_2$, H_2O, moderate aeration	2.8-9.3	28 (83)	...	0.05 (2) max	...	68
Hastelloy C	...	...	Plus 1% HF, 3% Na_2SO_4, 1% $SiO_2.2H_2O_2$, 0.5% Na_2SiF_6, balance water in separation of Na_2SiF_6	9	27-49 (80-120)	...	0.05 (2) max	...	68
Hastelloy C	...	...	Plus 1-2% Cu, 7000 oz/ton Ag, 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu, Traces Ag, Au, Sb, Co	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy C	...	...	Plus 1.6-4.8% $CuSO_4$ for flash pickling of brass parts	19-28	60 (140)	...	0.04 (1.6)	...	68
Hastelloy C	...	...	Plus 10% CuSO	10	70 (158)	...	0.38 (15)	...	68
Hastelloy C	...	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	0.5 (20) min	...	
Hastelloy C	...	...	Plus 10% $FeSO_4$	10	70 (158)	...	0.9 (34)	...	68
Hastelloy C	...	...	Plus 10% Na_2SO_4.	10	70 (158)	...	0.2 (8)	...	68
Hastelloy C	...	...	Plus 10% sulfate	10	70 (158)	...	1.3 (50) min	...	68
Hastelloy C	...	...	Plus 10-12% Na_2SO_4	10-12	349 (660)	...	0.002 (0.1)	...	68
Hastelloy C	...	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	0.05 (2) max	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy C	...	...	Plus 13% by volume $MnSO_4$ and Mn_2O_3 in process for leaching crude MnO_2	13	27-99 (80-210)	...	0.5 (18)	...	68
Hastelloy C	...	...	Plus 15-25% Na_2SO_4, 1-5% organic salts	5-15	45-55 (113-131)	...	0.004 (0.2)	...	68
Hastelloy C	...	...	Plus 2% Fe (ferrous and ferric in spray pickling machine)	20	77-82 (170-180)	...	0.4 (17)	...	68
Hastelloy C	...	...	Plus 20 oz. $Na_2Cr_2O_7$ per 18 gal	5	21-29 (70-85)	...	0.0017 (0.07)	...	68
Hastelloy C	...	...	Plus 3% $Al_2(SO_4)$, 1% $Fe_2(SO_4)_3$, traces of $CaSO_4$ and $MgSO_4$	7.5-8	93-99 (200-210)	...	0.04 (1.6)	...	68
Hastelloy C	...	...	Plus 3-4% zirconyl sulfate	5	32 (90)	15 d	0.05 (2) max	...	68
Hastelloy C	...	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.05 (2) max	...	68
Hastelloy C	...	...	Plus $CO_2(SO_4)_3$, $FeSO_4$, trace $CuSO_4$.	20	15-90 (59-194)	...	0.3 (12)	...	68
Hastelloy C	...	...	Plus Cu, 10-60 g/L (40 avg); Ag, 0-12 g/L (3.5 avg). Solids consist of precious metals, silica, $PbSO_4$, and a few % or less of Se, Te, As, Sb and Bi	5-150 g/L	71 (160)	...	0.05 (2) max	...	68
Hastelloy C	...	...	Plus $CuSO_4$ to saturation	0.4-8.0	77-104 (170-220)	...	0.015 (0.6)	...	68
Hastelloy C	...	...	Plus Na_2SO_4 and glucose in rayon spin bath	10	45 (113)	...	0.005 (0.2)	...	68
Hastelloy C	...	...	Plus ore containing MnO and MnO_2	5	82 (180)	...	0.05 (2) max	...	68
Hastelloy C	...	...	Plus sulfate oils, traces of NaCl and Na_2SO_4	5	50 (122)	...	0.007 (0.3)	...	68
Hastelloy C	...	...	Plus vegetable fats, greases	1-5	104 (220)	...	Resistant	...	68
Hastelloy C	...	...	Reacts with Fe_2O_3 to produce $Fe_2(SO_4)_3$, field test, aeration, moderate agitation, 6 ft/s	10-15	112 (234)	10 d	0.25 (10) max	...	68
Hastelloy C	...	...	Saturated with $CuSO_4$. Pickling copper and brass. Aeration, moderate agitation	20	60 (140)	120 d	0.25 (10)	...	68
Hastelloy C	...	...	Saturated with SO_2. Slight aeration	14-16	79 (175)	...	0.5 (20) min	...	68
Hastelloy C	...	...	SO_2 purge	10	38 (100)	...	0.05 (2) max	...	
Hastelloy C	...	...	SO_2 purge	10	65 (150)	...	0.25 (10) max	...	68
Hastelloy C	...	...	SO_2 purge	10	93 (200)	...	1.3 (50) min	...	68
Hastelloy C	...	...	SO_2 purge	10	Boiling	...	1.3 (50) min	...	68
Hastelloy C	...	...	Spent pickle solutions. Cold wash water with salts picked up in steel pickling (0.097% ferrous, 0.003% ferric)	0.26	Room	...	0.001 (0.05)	...	68
Hastelloy C	...	...	Steel pickling tank	8	49-60 (120-140)	...	0.12 (4.7)	...	68
Hastelloy C	...	...	To 5% (final before discarding), 0.09% (original) to 0.54% (final) $FeSO_4$. Inhibited with Activol 3591	16	74 (165)	...	0.5 (20) min	...	68
Hastelloy C	...	...	Top of acid spray section of conveyor-type spray pickling machine	12	85-91 (105-195)	...	0.1 (4)	...	68
Hastelloy C	...	...	Zr-HF separatio	20	Room	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	...	10	93 (200)	672 h	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Aeration, lab test	5	58-67 (137-153)	29.5 d	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	As scrubbing liquid, moderate aeration	1-23	150 (302)	...	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	Dicyclopentadiene hydrate reaction. Pilot plant	15	115-130 (238-266)	220 h	1.3 (50) min	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy C-276	N10276	...	Hot H_2S_4, pH 3.0, containing tungsten and molybdenum salts with 2-3 g/L fluorides, moderate aeration.	0-4	60 (140)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	In pickling stainless foil plus 3% HCl. First pickle is followed by 15 min in 10% cold HNO_3	18	77-82 (170-180)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Lab test	10	Boiling	120 h	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Nickel sulfide impurities	10	107 (225)	240 h	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	Plus 0-5% Na_2SO_4, 0-0.05% $ZnSO_4$, 0.02% CS_3, trace of H_2S.	0-3	93 (200)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 0.04% SO_2, and varying amounts of carbon on bottom tray of SO_2 scrubber in regeneration of alkylation acid	0.1	73-81 (164-177)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 0.1% $CuSO_4$ and some alcohols	2.5	93-121 (200-250)	...	0.25 (10)	...	68
Hastelloy C-276	N10276	...	Plus 0.35 oz/gal $NaNO_3$	6-9	68-79 (155-175)	...	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	Plus 0.5-3.5% $CuSO_4$ and abrasive anode mud from electrolytic copper refining	20-30	77-82 (170-180)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus 0.50-0.56 oz/gal Cu	5	80-85 (175-185)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 0.8-0.9 oz/gal $NaNO_3$ in pickling tank	7-8	68-74 (155-165)	...	0.25 (10)	...	68
Hastelloy C-276	N10276	...	Plus 0.8-5.3% $AlSO_4$, 0-0.3% $KCr(SO_4)_2.H_2O$, moderate aeration.	2.8-9.3	28 (83)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 1% HF, 3% Na_2SO_4, 1% $SiO_2.2H_2O_2$, 0.5% Na_2SiF_6, balance water in separation of Na_2SiF_6	9	27-49 (80-120)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 1-2% Cu, 7000 oz/ton Ag. 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu. Traces Ag, Au, Sb, Co	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 1.6-4.8% $CuSO_4$ for flash pickling of brass parts	19-28	60 (140)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 10% $CuSO_4$	10	70 (158)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus 10% $FeSO_4$	10	70 (158)	...	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	Plus 10% Na_2SO_4	10	70 (158)	...	0.25 (10)	...	68
Hastelloy C-276	N10276	...	Plus 10% sulfate	10	70 (158)	...	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	Plus 10-12% Na_2SO_4	10-12	349 (660)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 13% by volume $MnSO_4$ and Mn_2O_3 in process for leaching crude MnO_2	13	27-99 (80-210)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus 15-25% Na_2SO_4, 1-5% organic salts	5-15	45-55 (113-131)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 2% Fe (ferrous and ferric in spray pickling machine)	20	77-82 (170-180)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus 20 oz $Na_2Cr_2O_7$ per 18 gal	5	21-29 (70-85)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 3% $Al_2(SO_4)$, 1% $Fe_2(SO_4)_3$, traces of $CaSO_4$ and $MgSO_4$	7.5-8	93-99 (200-210)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 3-4% zirconyl sulfate	5	32 (90)	15 d	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.05 (2) max	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy C-276	N10276	...	Plus $Co_2(SO_4)_3$, $FeSO_4$, trace $CuSO_4$	20	15-90 (59-194)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Plus Cu, 10-60 g/L (40 avg); Ag, 0-12 g/L (3.5 avg). Solids consist of precious metals, silica, $PbSO_4$, and a few % or less of Se, Te, As, Sb and Bi	5-150 g/L	71 (160)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus $CuSO_4$ to saturation	0.4-8.0	77-104 (170-220)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus Na_2SO_4 and glucose in rayon spin bath	10	45 (113)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus ore containing MnO and MnO_2	5	82 (180)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus sulfate oils, traces of NaCl and Na_2SO_4	5	50 (122)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Plus vegetable fats, greases	1-5	104 (220)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Reacts with Fe_2O_3 to produce $Fe_2(SO_4)_3$. field test, aeration, moderate agitation, 6 ft/s	10-15	112 (234)	10 d	0.25 (10)	...	68
Hastelloy C-276	N10276	...	Saturated with $CuSO_4$. Pickling copper and brass. Aeration, moderate agitation	20	60 (140)	120 d	0.25 (10)	...	68
Hastelloy C-276	N10276	...	Saturated with SO_2. Slight aeration	14-16	79 (175)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	SO_2 purge	10	38 (100)	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	SO_2 purge	10	65 (150)	...	0.25 (10)	...	68
Hastelloy C-276	N10276	...	SO_2 purge	10	93 (200)	...	1.3 (50) min	...	68
Hastelloy C-276	N10276	...	SO_2 purge	10	Boiling	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Spent pickle solutions. Cold wash water with salts picked up in steel pickling (0.097% ferrous, 0.003% ferric)	0.26	Room	...	0.05 (2) max	...	68
Hastelloy C-276	N10276	...	Steel pickling tank	8	49-60 (120-140)	...	0.25 (10)	...	68
Hastelloy C-276	N10276	...	To 5% (final before discarding), 0.09% (original) to 0.54% (final) $FeSO_4$. Inhibited with Activol 3591	16	74 (165)	...	0.5 (20) min	...	68
Hastelloy C-276	N10276	...	Top of acid spray section of conveyor-type spray pickling machine	12	85-91 (105-195)	...	0.05 (10)	...	68
Hastelloy C-276	N10276	...	Zr-HF separation	20	Room	...	0.05 (2) max	...	68
Hastelloy C-4	N06455	Heat treated at 1066°C (1950°F), water quenched	...	10	Boiling	...	0.6 (22)	...	68
Hastelloy C-4	N06455	Gas tungsten arc welded	...	10	Boiling	...	0.6 (25)	...	68
Hastelloy C-4	N06455	Aged 100 h at 899°C (1650°F)	...	10	Boiling	...	0.5 (20)	...	68
Hastelloy C-4	N06455	Heat treated at 1066°C (1950°F), water quenched	...	85	75 (167)	...	0.6 (23)	...	68
Hastelloy C-4	N06455	Gas tungsten arc welded	...	85	75 (167)	...	0.4 (17)	...	68
Hastelloy C-4	N06455	Aged 10 h at 899°C (1650°F)	...	85	75 (167)	...	0.5 (21)	...	68
Hastelloy G	N06007	...	0.057% HCl, pH 2 to 5, incineration of municipal waste	0.19	60 (140)	2360 h	0.05 (2) max	...	68
Hastelloy G	N06007	...	3% chromic acid in deionized water	10	80 (175)	...	0.05 (2) max	...	68
Hastelloy G	N06007	...	3% chromic acid in deionized water	10	80-82 (175-180)	...	0.05 (2) max	...	68
Hastelloy G	N06007	...	Aeration, lab test	5	58-67 (137-153)	29.5 d	0.05 (2) max	...	68

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy G	N06007	...	As scrubbing liquid, moderate aeration	1-23	150 (302)	...	1.3 (50) min	...	68
Hastelloy G	N06007	...	Lab test	10	Boiling	120 h	0.5 (20) min	...	68
Hastelloy G	N06007	...	Plus 1-2% Cu, 7000 oz/ton Ag, 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu, Traces Ag, Au, Sb, Co	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy G	N06007	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	0.05 (2) max	...	68
Hastelloy G	N06007	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy G	N06007	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.05 (2) max	...	68
Hastelloy G	N06007	...	Reacts with Fe_2O_3 to produce $Fe_2(SO_4)_3$, field test, aeration, moderate agitation, 6 ft/s	10-15	112 (234)	10 d	0.05 (2) max	...	68
Hastelloy G	N06007	...	SO_2 purge	10	38 (100)	...	0.05 (2) max	...	68
Hastelloy G	N06007	...	SO_2 purge	10	65 (150)	...	0.05 (2) max	...	68
Hastelloy G	N06007	...	SO_2 purge	10	93 (200)	...	0.05 (2) max	...	68
Hastelloy G	N06007	...	SO_2 purge	10	Boiling	...	1.27 (50) min	...	68
Hastelloy G-3	N06985	...	0.057% HCl, pH 2-5, incineration of municipal waste	0.19	60 (140)	2360 h	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	3% chromic acid in deionized water	10	80 (175)	...	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	3% chromic acid in deionized water	10	80-82 (175-180)	...	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	Aeration, lab test	5	58-67 (137-153)	29.5 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	As scrubbing liquid	1-23	150 (302)	...	1.27 (50) min	...	68
Hastelloy G-3	N06985	...	Lab test	10	Boiling	120 h	0.5 (20) min	...	68
Hastelloy G-3	N06985	...	Plus 1-2% Cu, 7000 oz/ton Ag, 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu, Traces Ag, Au, Sb, Co	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	Plus 10% $CuSO_4$, 52 ppm Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	Reacts with Fe_2O_3 to produce $Fe_2(SO_4)_3$, field test, aeration, moderate agitation, 6 ft/s	10-15	112 (234)	10 d	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	SO_2 purge	10	38 (100)	...	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	SO_2 purge	10	65 (150)	...	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	SO_2 purge	10	93 (200)	...	0.05 (2) max	...	68
Hastelloy G-3	N06985	...	SO_2 purge	10	Boiling	...	1.27 (50) min	...	68
Hastelloy G-30	N06030	...	...	2	Boiling	...	0.2 (8)	...	63
Hastelloy G-30	N06030	...	...	10	Boiling	...	0.8 (31)	...	63
Hastelloy G-30	N06030	...	...	20	Boiling	...	1.4 (54)	...	63
Hastelloy G-30	N06030	...	...	50	107 (225)	...	0.9 (37)	...	63
Hastelloy G-30	N06030	...	...	80	52 (125)	...	0.3 (12)	...	63
Hastelloy G-30	N06030	...	...	99	130 (226)	...	1.1 (43)	...	63
Hastelloy G-30	N06030	...	...	99	140 (284)	...	1.2 (46)	...	63
Hastelloy G-30	N06030	...	...	99	130 (266)	96 h	1.05 (42)	...	224
Hastelloy G-30	N06030	...	...	98	110 (230)	...	0.43 (17)	...	225
Hastelloy G-30	N06030	...	...	10	Boiling	...	0.30 (12)	...	225
Hastelloy G-30	N06030	...	Nitric acid plus 11% HCl	25	80 (176)	...	0.6 (23)	...	63
Hastelloy G-30	N06030	...	Nitric acid plus 3% HCl	59	80 (176)	...	0.1 (5)	...	63
Hastelloy G-30	N06030	...	Nitric acid plus 8% HCl	18	80 (176)	...	0.05 (2)	...	63

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Hastelloy G-30	N06030	...	Plus 0.45% HCl	1.8	175 (347)	...	.003 (0.1)	...	225
Hastelloy G-30	N06030	...	Plus 0.45% HCl	3.5	175 (347)	...	.003 (0.1)	...	225
Hastelloy G-30	N06030	...	Plus 0.45% HCl	6.8	175 (347)	...	.008 (0.3)	...	225
Hastelloy G-30	N06030	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	0.01 (0.4)	...	224
Hastelloy G-30	N06030	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	0.005 (0.2)	...	224
Hastelloy G-30	N06030	...	Plus 1.3% HCl	5.0	175 (347)	...	.005 (0.2)	...	225
Hastelloy G-30	N06030	...	Plus 1.7% HCl	1.8	175 (347)	...	.003 (0.1)	...	225
Hastelloy G-30	N06030	...	Plus 10% nitric acid	50	Boiling	...	0.4 (16)	...	63
Hastelloy G-30	N06030	...	Plus 21.5% HNO_3	38.5	Boiling	...	0.25 (9.9)	...	225
Hastelloy G-30	N06030	...	Plus 26.3% HNO_3	47.1	Boiling	...	0.35 (14)	...	225
Hastelloy G-30	N06030	...	Plus 41.9% HNO_3	24.9	Boiling	...	0.28 (11)	...	225
Hastelloy G-30	N06030	...	Plus 42 g/L $Fe_2(SO_4)_3$	50	Boiling	...	0.2 (7)	...	63
Hastelloy G-30	N06030	...	Plus 5% nitric acid	60	Boiling	...	1.1 (45)	...	63
Hastelloy G-30	N06030	...	Plus 5% nitric acid	70	Boiling	...	3.4 (133)	...	63
Hastelloy G-30	N06030	...	Plus 55.9% HNO_3	12.5	Boiling	...	0.24 (9.4)	...	225
Hastelloy G-30	N06030	...	Plus 8% nitric acid plus 4% HF	77	54 (129)	...	0.01 (0.4)	...	63
Inco alloy G	N06007	...	...	10	Boiling	...	14 (0.4)	...	40
Inco alloy G	N06007	...	...	50	Boiling	...	108 (2.74)	...	40
Inco alloy G	N06007	...	Plus 3 vol% HCl + $FeCl_3$ + 1% $CuCl_2$	7	70 (158)	...	1200 (31)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	10	Boiling	7 d	20 (0.5)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	10	Boiling	7 d	23 (0.6)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	50	Boiling	7 d	49 (0.5)	...	40
Inco alloy G-3	N06985	...	Duplicate specimens	50	Boiling	7 d	23 (0.6)	...	40
Inco alloy G-3	N06985	...	Plus 3 vol% HCl + $FeCl_3$ + 1% $CuCl_2$	7	70 (158)	24 h	30 (0.8)	...	40
Inco alloy G-3	N06985	...	Plus 3 vol% HCl + $FeCl_3$ + 1% $CuCl_2$	7	70 (158)	24 h	40 (1.0)	...	40
Incoloy 825	N08825	...	12% sulfuric acid pickling solution containing copper sulfate up to 11.2%. Immersed inside tank of Mesta pickler	...	82 (180)	26 d	0.005 (0.2)	...	43
Incoloy 825	N08825	...	28% oxalic acid, 32% water and 4% ash. On agitator support in vacuum evaporation plan. Alternately immersed and exposed	36	60 (140)	171 d	0.06 (2.4)	...	43
Incoloy 825	N08825	...	Aqueous solution	0.5	99 (120)	45 d	0.05 (2.0)	...	43
Incoloy 825	N08825	...	Evaporation of aluminum sulfate solution from 28.2 to 57.7% $Al_2(SO_4)_3$, containing 0.1% Fe_2O_3, 0.3% FeO, and traces of Cr_2O_3 and Al_2O_3	...	91-121 (195-250)	44 d	0.02 (0.8)	...	43
Incoloy 825	N08825	...	In uranium ore leach tank in mixture containing 60% solids, 5-10 g/L ferric ion, some ferrous ion, 0.1% sodium chlorate	28-55 g/L	45 (113)	41 d	0.003 (0.1)	...	43
Incoloy 825	N08825	...	In vacuum evaporator. Recovery of sulfuric acid in paper making	39	49 (120)	120 d	Resistant	...	43
Incoloy 825	N08825	...	In vacuum evaporator. Recovery of sulfuric acid in paper making	42	57 (135)	120 d	0.008 (0.3)	...	43
Incoloy 825	N08825	...	In vacuum evaporator. Recovery of sulfuric acid in paper making	55	71 (160)	120 d	0.1 (4.0)	...	43
Incoloy 825	N08825	...	Mixture of sulfuric acid and sebacic acid pH 1	...	Room	30 d	0.003 (0.1)	...	43

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Incoloy 825	N08825	...	Plus 0.25% copper sulfate in pickling of brass. Immersed in continuous strip pickler	5-10	38-93 (100-200)	162 d	0.003 (0.1)	...	43
Incoloy 825	N08825	...	Plus 1% hydrofluoric acid, 3% sodium sulfate, 1% silica, 0.5% sodium fluosilicate and balance water. Immersed in tank near entrance	9	27-49 (80-120)	62 d	0.03 (1)	...	43
Incoloy 825	N08825	...	Plus 10-300 mesh ore of MnO_2 and MnO. Attached to steam coil in leaching tank	5	82 (180)	245 d	0.01 (0.5)	...	43
Incoloy 825	N08825	...	Plus 100 g/L $CuSO_4$, 10 g/L $NiSO_4$, and trace of chloride. Treatment of copper residue in nickel refining. Immersed in concentration-plant air blowers	20	91 (195)	7 d	0.1 (5)	...	43
Incoloy 825	N08825	...	Plus 20-25% ammonium sulfate plus 10-15% sodium sulfate. Immersed in tank	1-4	35-40 (95-104)	...	0.003 (0.1)	...	43
Incoloy 825	N08825	...	Plus 22% nitric acid and 19% water. Immersed in lab tests	50	66 (150)	6 d	0.01 (0.5)	...	43
Incoloy 825	N08825	...	Plus 22% nitric acid and 19% water. Immersed in lab tests	50	83 (182)	5 d	0.1 (4.3)	...	43
Incoloy 825	N08825	...	Plus 25-100 g/L $MnSO_4$, 1-3 g/L $Fe_2(SO_4)_3$. Immersed in sump in MnO_2 electrolysis circuit. Flow 100 gal/min (380 L/min)	25-50 g/L	93 (200)	119 d	0.07 (2.8)	...	43
Incoloy 825	N08825	...	Plus 3.5% hydrogen peroxide plus various salts of iron, manganese, chromium and nickel in holding tank	78	38-54 (100-130)	8 d	0.1 (5.0)	...	43
Incoloy 825	N08825	...	Plus 4% sodium dichromate. Immersed in cleaning solution for aluminum	20	66-71 (150-160)	77 d	0.5 (19)	...	43
Incoloy 825	N08825	...	Plus 40-100 g/L selenious acid, small amount sulfurous acid.	100-200 g/L	21-27 (70-80)	90 d	Resistant	...	43
Incoloy 825	N08825	...	Plus 91.6% benzene sulfonic acid. Immersed in glass-lined vessel	3.5	60 (140)	7 d	1.1 (45)	...	43
Incoloy 825	N08825	...	Plus gas mixture containing 44% propylene and 56% propane. In outlet piping from second stage reactor circulating pumps, pressure 400 psi (2.8 MPa)	67	52 (125)	170 d	0.005 (0.2)	...	43
Incoloy 825	N08825	...	Plus small amounts of phosphine, ammonia and hydrogen sulfate. In exit of packed tower in falling acid strea	79-93	10-32 (50-90)	189 d	0.06 (2.2)	...	43
Incoloy 825	N08825	...	Plus traces of benzene sulfonic acid in bottom of acid settling tank	78	38-54 (100-130)	56 d	0.01 (0.5)	...	43
Incoloy 825	N08825	...	Spent acid liquor from tall oil splitting. Plus 1% tall oil and 2-3% lignin by volume. Acid discharge line from centrifuge	1	121 (250)	33 d	0.003 (0.1)	...	43
Inconel 600	N06600	...	Air saturated. Velocity, 15.5 fpm	5	30 (86)	20 h	...	...	64
Inconel 600	N06600	...	Air-saturated	0.16	100 (212)	...	...	...	64
Inconel 600	N06600	...	Air-saturated Velocity, 15.5 fpm	1	30 (86)	120 h	1.2 (49)	...	64
Inconel 600	N06600	...	Air-saturated Velocity, 16.0 fpm	5	30 (86)	23 h	2.0 (78)	...	64
Inconel 600	N06600	...	Air-saturated Velocity, 16.0 fpm	5	80 (176)	20 h	3.8 (150)	...	64
Inconel 600	N06600	...	Air-saturated Velocity, none	5	18 (65)	100 h	...	...	64
Inconel 600	N06600	...	Air-saturated Velocity, none	5	60 (140)	100 h	...	...	64

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Inconel 600	N06600	...	Air-saturated Velocity, none	10	...	24 h	...	...	64
Inconel 600	N06600	...	Air-saturated. Velocity, 15.5 fpm	1	78 (172)	22 h	2.8 (110)	...	64
Inconel 600	N06600	...	Air-saturated. Velocity, 15.5 fpm	70	30 86	20 h	...	...	64
Inconel 600	N06600	...	Air-saturated. Velocity, 15.5 fpm	93	30 (86)	20 h	0.3 (10)	...	64
Inconel 600	N06600	...	Unaerated	0.16	100 (212)	...	0.09 (3.7)	...	64
Inconel 600	N06600	...	Unaerated Velocity, 15.5 fpm	1	30 (86)	120 h	...	...	64
Inconel 600	N06600	...	Unaerated Velocity, 15.5 fpm	1	78 (172)	22 h	...	...	64
Inconel 600	N06600	...	Unaerated Velocity, 15.5 fpm	5	30 (86)	20 h	0.2 (9)	...	64
Inconel 600	N06600	...	Unaerated Velocity, 15.5 fpm	70	30 86	20 h	1.2 46	...	64
Inconel 600	N06600	...	Unaerated Velocity, 15.5 fpm	93	30 (86)	20 h	6.9 (270)	...	64
Inconel 600	N06600	...	Unaerated Velocity, 16.0 fpm	5	30 (86)	23 h	...	...	64
Inconel 600	N06600	...	Unaerated Velocity, 16.0 fpm	5	80 (176)	20 h	0.08 (30)	...	64
Inconel 600	N06600	...	Unaerated Velocity, none	5	18 (65)	100 h	0.06 (2.4)	...	64
Inconel 600	N06600	...	Unaerated Velocity, none	5	60 (140)	100 h	0.3 (10)	...	64
Inconel 600	N06600	...	Unaerated Velocity, none	10	...	24 h	0.1 4.2	...	64
Inconel 617	N06617	...	Average of two tests	5	80 (175)	...	...	...	44
Inconel 617	N06617	...	Average of two tests	5	Boiling	...	0.6 (24)	...	44
Inconel 617	N06617	...	Average of two tests	10	80 (175)	...	0.05 (2)	...	44
Inconel 617	N06617	...	Average of two tests	10	Boiling	...	0.7 (28)	...	44
Inconel 617	N06617	...	Average of two tests	20	80 (175)	...	0.8 (32)	...	44
Inconel 617	N06617	...	Average of two tests	20	Boiling	...	2.5 (97)	...	44
Inconel 617	N06617	...	Average of two tests	30	80 (175)	...	1.1 (44)	...	44
Inconel 617	N06617	...	Average of two tests	30	Boiling	...	12 (468)	...	44
Inconel 617	N06617	...	Average of two tests	40	80 (175)	...	1.0 (40)	...	44
Inconel 617	N06617	...	Average of two tests	40	Boiling	...	21 (838)	...	44
Inconel 617	N06617	...	Average of two tests	50	80 (175)	...	2.4 (94)	...	44
Inconel 617	N06617	...	Average of two tests	50	Boiling	...	...	...	44
Inconel 625	N06625	...	...	15	80 (176)	...	0.2 (7.4)	...	64
Inconel 625	N06625	...	...	50	80 (176)	...	0.4 (17)	...	64
Inconel 625	N06625	...	...	60	80 (176)	...	0.7 (28)	...	64
Inconel 625	N06625	...	...	70	80 (176)	...	1.6 (64)	...	64
Inconel 625	N06625	...	...	80	80 (176)	...	2.3 (90)	...	64
Inconel 706	N07702	...	Annealed	10	Boiling	...	3.1 (123)	...	146
Monel 400	N04400	...	...	5	101 (214)	23 h	0.09 (3.4)	...	134
Monel 400	N04400	...	...	10	102 (216)	23 h	0.06 (2.4)	...	134
Monel 400	N04400	...	...	19	104 (219)	23 h	0.2 (7.5)	...	134
Monel 400	N04400	...	...	50	123 (253)	20 h	17 (650)	...	134
Monel 400	N04400	...	...	75	182 (360)	20 h	58 (2300)	...	134
Monel 400	N04400	...	...	96	293 (560)	3 h	84 (3300)	...	134
Monel 400	N04400	...	Lab test. In autoclave under 50 psig pressure. Velocity, 17 fpm	39	158 (317)	...	25 (1000) min	...	64
Monel 400	N04400	...	Mixture of 1 part weak organic base and 3 parts 22% sulfuric acid solution in autoclave under 260 psig pressure	22	225-230 (437-446)	272 h	4.8 (190)	...	64
Monel 400	N04400	...	Plus 12% pyroligneous liquor in pressure digestion of wood under 30 psig pressure	2	135 (275)	4 d	0.03 (1.3)	...	64
Monel 400	N04400	...	Plus 12% pyroligneous liquor in pressure digestion of wood under 30 psig pressure	10	170 (338)	19 d	0.08 (3.1)	...	64

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Monel 400	N04400	...	Plus precipitated basic alum in autoclave under 225 psig pressure. Pitted to maximum depth of 0.004 in.	10	200 (392)	14 d	1.4 (57)	...	64
Nickel 200	N02200	...	Air saturated. Velocity, 15.5 fpm	1	30 (86)	...	1.2 (49)	...	44
Nickel 200	N02200	...	Air saturated. Velocity, 15.5 fpm	1	78 (172)	...	2.8 (110)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, 15.0 fpm	10	60 (140)	...	2.3 (89)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, 16.0 fpm	5	30 (86)	...	1.5 (61)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, 16.0 fpm	5	71 (160)	...	2.6 (103)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, 16.0 fpm	50	30 (86)	...	0.4 (16)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, 26.0 fpm	25	82 (180)	...	2.1 (83)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	2	21 (70)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	5	18 (65)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	5	60 (140)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	10	21 (70)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	10	77 (170)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	10	80 (176)	...	3.0 (120)	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	20	21 (70)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	48	70 (158)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	93	65 (149)	...	...	...	44
Nickel 200	N02200	...	Air-saturated Velocity, none	95	21 (70)	...	...	...	44
Nickel 200	N02200	...	Air-saturated. Velocity, 15.5 fpm	5	60 (140)	...	2.2 (88)	...	44
Nickel 200	N02200	...	Air-saturated. Velocity, 15.5 fpm	5	78 (172)	...	5 (200)	...	44
Nickel 200	N02200	...	Air-saturated. Velocity, none.	5	77 (170)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.0 fpm	10	60 (140)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	1	30 (86)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	1	78 (172)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	5	60 (140)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	5	78 (172)	...	0.8 (30)	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	70	38 (100)	...	0.7 (29)	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	70	38 (100)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	93	30 (86)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 15.5 fpm	93	30 (86)	...	0.3 (10)	...	44
Nickel 200	N02200	...	Unaerated Velocity, 16.0 fpm	5	30 (86)	...	0.2 (9)	...	44
Nickel 200	N02200	...	Unaerated Velocity, 16.0 fpm	5	71 (160)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 16.0 fpm	50	30 (86)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, 26.0 fpm	25	82 (180)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	2	21 (70)	...	0.05 (2)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	5	18 (65)	...	0.06 (2.2)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	5	60 (140)	...	0.3 (10)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	5	77 (170)	...	0.05 (21)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	10	21 (70)	...	0.04 (1.7)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	10	77 (170)	...	0.3 (12)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	10	80 (176)	...	...	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	20	21 (70)	...	0.1 (4)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	48	70 (158)	...	0.5 (18)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	93	65 (149)	...	3.7 (146)	...	44
Nickel 200	N02200	...	Unaerated Velocity, none	95	21 (70)	...	1.8 (71)	...	44
Sanicro 28	N08028	...	...	10	Boiling	...	2.08 (83)	...	212
Sanicro 28	N08028	...	...	60	Boiling	...	1.08 (43)	...	212
Sanicro 28	N08028	...	...	56	Boiling	...	0.18 (7)	...	212

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
44Co-31Cr-13W	...	As cast	...	25	65 (150)	...	25.4 (1000) min	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	25	65 (150)	...	25 (1000) min	...	53
44Co-31Cr-13W	...	As cast	...	25	66 (150)	24 h	25.4 (1000) min	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	25	66 (150)	24 h	25.4 (1000) min	...	53
44Co-31Cr-13W	...	As cast	...	77	Room	...	Resistant	...	53
44Co-31Cr-13W	...	As cast	...	77	Room	24 h	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	77	Room	24 h	...	...	53
44Co-31Cr-13W	...	As cast	...	96	Room	...	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	96	Room	...	0.01 (0.3)	...	53
44Co-31Cr-13W	...	As cast	...	96	Room	24 h	Resistant	...	53
44Co-31Cr-13W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	96	Room	24 h	0.01 (0.3)	...	53
50Co-20Cr-15W-10Ni	...	...	...	25	65 (150)	...	0.3 (11)	...	53
50Co-20Cr-15W-10Ni	...	...	...	25	65 (150)	...	0.3 (11)	...	53
50Co-20Cr-15W-10Ni	...	...	...	77	Room	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	...	...	77	Room	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	...	...	96	Room	...	Resistant	...	53
50Co-20Cr-15W-10Ni	...	...	...	96	Room	...	Resistant	...	53
53Co-30Cr-4.5W	...	As cast	...	25	65 (150)	...	0.03 (1)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F)	...	25	65 (150)	...	0.03 (1)	...	53
53Co-30Cr-4.5W	...	As cast	...	25	65 (150)	24 h	0.03 (1)	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	25	65 (150)	24 h	0.03 (1)	...	53
53Co-30Cr-4.5W	...	As cast	...	77	Room	...	Resistant	...	53
53Co-30Cr-4.5W	...	As cast	...	77	Room	24 h	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	77	Room	24 h	...	...	53
53Co-30Cr-4.5W	...	As cast	...	96	Room	...	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F)	...	96	Room	...	Resistant	...	53
53Co-30Cr-4.5W	...	As cast	...	96	Room	24 h	Resistant	...	53
53Co-30Cr-4.5W	...	Heat treated 4 h at 899°C (1650°F) and furnace cooled	...	96	Room	24 h	Resistant	...	53
67Zr-33Ni	...	Crystalline	...	...	22-25	600 h	.002 (0.08)	...	204
67Zr-33Ni	...	Amorphous	...	...	22-25	600 h	.001 (.04) max	...	204

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cb alloy, wrought 0.75% Zr, bal Cb	R04261	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	30	Boiling	48 h	0.3 (10)	Embrittled	33
Cb alloy, wrought 0.75% Zr, bal Cb	R04261	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	50	Boiling	48 h	0.9 (36)	Embrittled	33
Cb alloy, wrought 0.75% Zr, bal Cb	R04261	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	60	Boiling	48 h	1.7 (68)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h test periods	30	Boiling	48 h	0.3 (11)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	30	Boiling	48 h	0.2 (9)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	30	Boiling	48 h	0.2 (9)	...	33
Cb alloy, wrought 100% Cb	R04210	Lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h test periods	50	Boiling	48 h	0.8 (32)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	50	Boiling	48 h	0.6 (23)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	50	Boiling	48 h	0.9 (34)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Lab button; annealed at 1175°C (2140°F) for 30 min	Average of three 48-h test periods	60	Boiling	48 h	1.8 (70)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	60	Boiling	48 h	1.7 (69)	Embrittled	33
Cb alloy, wrought 100% Cb	R04210	Electron-beam melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	60	Boiling	48 h	1.6 (64)	...	33
Cb alloy, wrought 50% V, 50% Cb	...	Arc melted	Average of three 48-h test periods	30	Boiling	48 h	1.6 (63)	Embrittled	33
Cb alloy, wrought 6.9% Ti, 0.81% Zr, bal Cb	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	30	Boiling	48 h	0.4 (15)	...	33
Cb alloy, wrought 6.9% Ti, 0.81% Zr, bal Cb	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	50	Boiling	48 h	5 (187)	...	33
Cb alloy, wrought 8% Ti, bal Cb	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	30	Boiling	48 h	0.3 (13)	...	33

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cb alloy, wrought 8% Ti, bal Cb	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	50	Boiling	48 h	1.6 (63)	...	33
Cb alloy, wrought 8% Ti, bal Cb	...	Arc melted; annealed at 1400°C (2552°F) for 1 h	Average of three 48-h test periods	60	Boiling	48 h	2.9 (114)	...	33
Chromium	...	...	...	30	Boiling	50 h	22000 (8690000)	...	245
Chromium + 0.5Pd	...	...	...	30	Boiling	50 h	.53 (21)	...	245
Chromium + 0.5Pt	...	...	...	30	Boiling	50 h	.67 (26)	...	245
Co-20Cr	...	...	...	11	Boiling	...	110 (4400)	...	35
Co-Cr-Ni	R31233	Welding rod	...	2	Boiling	...	0.41 (16)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with G10400	...	2	Boiling	...	0.69 (28)	...	196
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	2	Boiling	...	0.58 (23)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with S31603	...	2	Boiling	...	0.84 (34)	...	196
Co-Cr-Ni	R31233	Diluted 16.7% with S31603	...	2	Boiling	...	0.48 (19)	...	196
Co-Cr-Ni	R31233	Welding rod	...	10	Boiling	...	2.5 (100)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with G10400	...	10	Boiling	...	3.8 (152)	...	196
Co-Cr-Ni	R31233	Diluted 16.9% with G10400	...	10	Boiling	...	3.1 (124)	...	196
Co-Cr-Ni	R31233	Diluted 9.1% with S31603	...	10	Boiling	...	4.2 (168)	...	196
Co-Cr-Ni	R31233	Diluted 16.7% with S31603	...	10	Boiling	...	3.2 (128)	...	196
Cobalt	...	...	Static	5	25 (77)	...	0.2 (9)	...	54
Hafnium	...	...	...	60	...	8 d	0.005 (0.2)	...	11
Hafnium	...	...	...	60	...	8 d	0.005 (0.2)	...	11
Haynes No.25	R30605	Solution heat treated	...	2	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	2	66 (150)	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	2	Boiling	24 h	1.2 (49)	...	68
Haynes No.25	R30605	Solution heat treated	...	5	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	5	66 (150)	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	5	Boiling	24 h	1.3 (52)	...	68
Haynes No.25	R30605	Solution heat treated	...	10	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	10	66 (150)	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	10	Boiling	24 h	2.3 (92)	...	68
Haynes No.25	R30605	Solution heat treated	...	25	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	25	66 (150)	24 h	0.3 (11)	...	68
Haynes No.25	R30605	Solution heat treated	...	25	Boiling	24 h	5.2 (203)	...	68
Haynes No.25	R30605	Solution heat treated	...	50	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	50	66 (150)	24 h	0.8 (30)	...	68

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Haynes No.25	R30605	Solution heat treated	...	50	Boiling	24 h	25 (1000) min	...	68
Haynes No.25	R30605	Solution heat treated	...	60	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	60	66 (150)	24 h	0.7 (29)	...	68
Haynes No.25	R30605	Solution heat treated	...	60	Boiling	24 h	25 (1000) min	...	68
Haynes No.25	R30605	Solution heat treated	...	77	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	77	66 (150)	24 h	1.4 (55)	...	68
Haynes No.25	R30605	Solution heat treated	...	77	Boiling	24 h	25 (1000) min	...	68
Haynes No.25	R30605	Solution heat treated	...	80	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	80	66 (150)	24 h	1.6 (61)	...	68
Haynes No.25	R30605	Solution heat treated	...	80	Boiling	24 h	25 (1000) min	...	68
Haynes No.25	R30605	Solution heat treated	...	85	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	85	66 (150)	24 h	2.3 (91)	...	68
Haynes No.25	R30605	Solution heat treated	...	85	Boiling	24 h	25 (1000) min	...	68
Haynes No.25	R30605	Solution heat treated	...	90	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	90	66 (150)	24 h	3 (123)	...	68
Haynes No.25	R30605	Solution heat treated	...	90	Boiling	24 h	19 (735)	...	68
Haynes No.25	R30605	Solution heat treated	...	96	Room	24 h	Resistant	...	68
Haynes No.25	R30605	Solution heat treated	...	96	66 (150)	24 h	3 (104)	...	68
Haynes No.25	R30605	Solution heat treated	...	96	Boiling	24 h	8 (318)	...	68
Niobium	R04210	...	...	1	190 (375)	...	0.02 (1) max	...	37
Niobium	R04210	...	...	1	190 (375)	...	0.02 (1) max	...	37
Niobium	R04210	...	...	5	190 (375)	...	0.02 (1) max	...	37
Niobium	R04210	...	...	10	Boiling	...	0.1 (5) max	...	37
Niobium	R04210	...	...	10	190 (375)	...	0.2 (10) max	...	37
Niobium	R04210	...	...	20	190 (375)	...	0.7 (30) max	...	37
Niobium	R04210	...	...	30	Boiling	...	0.4 (15) max	...	37
Niobium	R04210	...	...	30	190 (375)	...	1.2 (50) min	...	37
Niobium	R04210	...	...	40	190 (375)	...	2.5 (100) min	...	37
Niobium	R04210	...	...	50	Boiling	...	1.2 (50) max	...	37
Niobium	R04210	...	...	50	190 (375)	...	7.6 (300) min	...	37
Niobium	R04210	...	...	60	190 (375)	...	10 (400) min	...	37
Niobium	R04210	...	...	70	Boiling	...	6.4 (250) min	...	37
Niobium	R04210	...	...	5-40	Room	...	Resistant	...	2
Niobium	R04210	...	...	10	Boiling	...	0.1 (5.0)	...	2
Niobium	R04210	...	...	20	94-100 (205-212)	...	0.003 (0.1) max	...	74
Niobium	R04210	...	...	25	Boiling	...	0.3 (10)	...	2
Niobium	R04210	...	...	40	Boiling	...	0.5 (20)	...	2
Niobium	R04210	...	...	60	Boiling	...	1.3 (50)	...	2
Niobium	R04210	...	...	98	Room	...	Questionable	Embrittled	2
Niobium	R04210	...	...	98	19-26 (65-80)	36 d	0.0005 (0.02)	...	74

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium	R04210	...	...	1	Boiling	11 d	Resistant	...	229
Niobium	R04210	...	...	10	Boiling	11 d	.006 (.24)	...	229
Niobium	R04210	...	...	20	Boiling	11 d	.030 (1.2)	...	229
Niobium	R04210	...	...	40	Boiling	11 d	.094 (3.8)	...	229
Niobium	R04210	...	...	60	Boiling	11 d	.34 (13.6)	...	229
Niobium	R04210	...	...	80	Boiling	11 d	15 (600)	...	229
Niobium	R04210	...	...	20	50	350 h	.002 (.08)	...	229
Niobium	R04210	...	...	20	100	350 h	.040 (1.6)	...	229
Niobium	R04210	...	...	50		350 h	.095 (3.8)	...	229
Niobium	R04210	...	...	80		350 h	.25 (10)	...	229
Niobium	R04210	...	...	98		350 h	2.6 (104)	...	229
Niobium	R04210	...	...	80	150	350 h	3.4 (136)	...	229
Niobium	R04210	...	...	98		350 h	30 (1200)	...	229
Niobium	R04210	...	...	20	150	...	.21 (8.4)	...	229
Niobium	R04210	...	...	30	150	...	.33 (13.2)	...	229
Niobium	R04210	...	...	40	150	...	.34 (13.6)	...	229
Niobium	R04210	...	...	50	150	...	.97 (39)	...	229
Niobium	R04210	...	...	60	150	...	1.00 (40)	...	229
Niobium	R04210	...	...	20	175	...	.21 (8.4)	...	229
Niobium	R04210	...	...	40	175	...	1.30 (52)	...	229
Niobium	R04210	...	Combined with 0.1 to 1% $FeCl_3$	60	Boiling	...	0.5 (20)	...	2
Niobium	R04210	...	Combined with 2% $FeCl_3$	40	Boiling	...	0.3 (10)	...	2
Niobium	R04210	...	Combined with 7% HCl and 100 ppm F^-	20	Boiling	...	0.3 (10)	...	2
Niobium	R04210	...	Plus 20% HNO_3	50	50-80 (120-175)	...	Resistant	...	2
Niobium	R04210	...	Plus 20% HNO_3	50	Boiling	...	0.3 (10)	...	2
Niobium	R04210	...	Plus 20% HNO_3	50	50 (122)	...	Resistant	...	61
Niobium	R04210	...	Plus 20% HNO_3	50	80 (176)	...	Resistant	...	61
Niobium	R04210	...	Plus 20% HNO_3	50	Boiling	...	0.2 (10)	...	61
Niobium	R04210	...	Plus 3% CrO_3	72	10 (212)	...	0.03 (1.0)	...	2
Niobium	R04210	...	Plus 3% CrO_3	72	125 (255)	...	0.01 (5.0)	...	2
Niobium	R04210	...	Plus 7% HCl + 100 ppm F^-	20	Boiling	...	0.2 (10)	...	61
Niobium	R04210	...	Plus 7% HCl + 50 ppm F^-	20	Boiling	4 d	0.2 (9)	...	61
Niobium	R04210	...	Plus with 3% CrO_3	72	Boiling	...	4 (150)	...	2
Niobium	R04210	...	Tarnished. Five 48-h test periods	98	145 (295)	30 d	4.6 (180)	...	74
Niobium-25Ta	...	...	...	1	Boiling	11 d	Resistant	...	229
Niobium-25Ta	...	...	...	20	Boiling	11 d	.003 (.12)	...	229
Niobium-25Ta	...	...	...	40	Boiling	11 d	.020 (.80)	...	229
Niobium-25Ta	...	...	...	60	Boiling	11 d	.195 (7.8)	...	229
Niobium-25Ta	...	...	...	80	Boiling	11 d	6 (240)	...	229
Niobium-25Ta	...	...	...	20	50	350 h	.001 (.04)	...	229
Niobium-25Ta	...	...	...	50		350 h	.003 (.12)	...	229
Niobium-25Ta	...	...	...	80		350 h	.004 (.16)	...	229
Niobium-25Ta	...	...	...	20	100	...	.002 (.08)	...	229
Niobium-25Ta	...	...	...	50	100	...	.040 (1.6)	...	229
Niobium-25Ta	...	...	...	80	100	...	.10 (4.0)	...	229
Niobium-25Ta	...	...	...	98	100	...	1.65 (6.6)	...	229
Niobium-25Ta	...	...	...	80	150	...	1.05 (42)	...	229
Niobium-25Ta	...	...	...	98	150	...	20 (800) min	...	229
Niobium-25Ta	...	...	...	20	150	...	.002 (.08)	...	229
Niobium-25Ta	...	...	...	30	150	...	.037 (1.5)	...	229
Niobium-25Ta	...	...	...	40	150	...	.063 (2.5)	...	229

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Niobium-25Ta	...	...	...	50	150	...	.10 (4.0)	...	229
Niobium-25Ta	...	...	...	60	150	...	.14 (5.6)	...	229
Niobium-25Ta	...	...	...	20	175	...	Resistant	...	229
Niobium-25Ta	...	...	...	40	175	...	0.12 (4.8)	...	229
Pure Titanium	...	...	...	1	Boiling	24 h	11.7 (460)	...	245
Pure Titanium	...	...	...	10	Boiling	24 h	100 (3900)	...	245
Pure Titanium	...	...	...	10	Boiling	24 h	1.2 (47)	...	245
Pure Titanium	...	...	...	10	Boiling	24 h	1.1 (43)	...	245
Ta-Mo alloy	...	...	Contains 10.1% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy	...	...	Contains 100% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Ta-Mo alloy	...	...	Contains 20.1% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy	...	...	Contains 30.0% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy	...	...	Contains 40.0% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	0.003 (0.1)	...	56
Ta-Mo alloy	...	...	Contains 50.0% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Ta-Mo alloy	...	...	Contains 61.2% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Ta-Mo alloy	...	...	Contains 71.5% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Ta-Mo alloy	...	...	Contains 82.8% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Ta-Mo alloy	...	...	Contains 91.4% Ta. Solutions saturated with oxygen	Conc	55 (131)	...	Resistant	...	56
Tantalum	R05210	...	...	...	70 (158)	...	Poor	...	42
Tantalum	R05210	...	...	1	Boiling	...	0.02 (1)	...	37
Tantalum	R05210	...	...	5	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	5	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	10	25 (76)	...	Resistant	...	42
Tantalum	R05210	...	...	20	94-100 (205-212)	4 d	Resistant	...	74
Tantalum	R05210	...	...	30	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	30	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	40	25 (76)	...	Resistant	...	42
Tantalum	R05210	...	...	50	19-26 (65-80)	35 d	Resistant	...	74
Tantalum	R05210	...	...	50	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	50	190 (375)	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	70	Boiling	...	0.02 (1) max	...	37
Tantalum	R05210	...	...	70	190 (375)	...	0.05 (2) max	...	37
Tantalum	R05210	...	...	75	Boiling	...	0.05 (2) max	...	37
Tantalum	R05210	...	...	75	190 (375)	...	0.05 (2) max	...	37
Tantalum	R05210	...	...	80	Boiling	...	0.12 (5) max	...	37
Tantalum	R05210	...	...	80	190 (375)	...	0.12 (5) max	...	37
Tantalum	R05210	...	...	85	Boiling	...	1.2 (50) max	...	37
Tantalum	R05210	...	...	85	190 (375)	...	0.05 (2) max	...	37
Tantalum	R05210	...	...	98	19-26 (65-80)	36 d	Resistant	...	74
Tantalum	R05210	...	...	98	21 (70)	...	Resistant	...	74
Tantalum	R05210	...	...	98	145 (295)	30 d	Resistant	...	74
Tantalum	R05210	...	...	98	175 (345)	30 d	0.003 (1) max	...	74
Tantalum	R05210	...	...	98	200 (390)	30 d	0.04 (1.5)	...	74
Tantalum	R05210	...	...	98	250 (480)	6 h	0.7 (29)	...	74

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Tantalum	R05210	...	...	98	300 (570)	...	9 (342)	...	74
Tantalum	R05210	...	...	98	25 (76)	...	Resistant	...	42
Tantalum	R05210	...	...	98	50 (122)	...	Resistant	...	42
Tantalum	R05210	...	...	98	100 (212)	...	Resistant	...	42
Tantalum	R05210	...	...	98	200 (392)	...	0.08 (3)	...	42
Tantalum	R05210	...	...	98	250 (482)	...	Poor	...	42
Tantalum	R05210	...	...	Conc	Boiling	...	75 (200) min	...	37
Tantalum	R05210	...	...	Conc	190 (375)	...	0.05 (2) max	...	37
Tantalum	R05210	...	Fuming 15% SO_3	...	23 (73)	...	0.01 (0.5)	...	42
Tantalum, commercial sheet	R05210	...	Average of three 48-h test periods	30	Boiling	48 h	0.025 (1) max	...	33
Tantalum, commercial sheet	R05210	...	Average of three 48-h test periods	50	Boiling	48 h	0.025 (1) max	...	33
Tantalum, commercial sheet	R05210	...	Average of three 48-h test periods	60	Boiling	48 h	0.025 (1) max	...	33
Tantalum, high purity	R05210	...	Average of three 48-h test periods	30	Boiling	48 h	0.025 (1) max	...	33
Tantalum, high purity	R05210	...	Average of three 48-h test periods	50	Boiling	48 h	0.025 (1) max	...	33
Tantalum, high purity	R05210	...	Average of three 48-h test periods	60	Boiling	48 h	0.025 (1) max	...	33
Ti-3-8-6-4-4	R58640	...	Naturally aerated	1	Boiling	...	Resistant	...	33
Ti-3-8-6-4-4	R58640	...	Naturally aerated	5	Boiling	...	1.9 (73)	...	33
Ti-3-8-6-4-4	R58640	...	Plus 1 g/L $FeCl_3$	10	Boiling	...	0.15 (6)	...	33
Ti-3-8-6-4-4	R58640	...	Plus 3% $Fe_2(SO_4)_3$	50	Boiling	...	0.03 (1.18) max	...	33
Ti-3-8-6-4-4	R58640	...	Plus 50 g/L $FeCl_3$	10	Boiling	...	0.05 (2.0)	...	33
Ti-3Al-2.5V, ASTM grade 9	...	...	...	0.5	Boiling	...	0.4 (334)	...	91
Titanium	...	...	...	0.5	Boiling	...	5.0 (200) min	...	91
Titanium	...	...	...	1	Boiling	...	18 (712)	...	90
Titanium	...	...	...	5	Boiling	...	25 (1016)	...	90
Titanium	...	...	...	50	19-26 (65-80)	35 d	0.05 (2.1)	...	74
Titanium	...	...	...	98	19-26 (65-80)	36 d	1.2 (47)	...	74
Titanium	...	...	...	98	145 (295)	30 d	Poor	...	74
Titanium	...	...	Aerated	1	60 (140)	...	0.01 (0.3)	...	90
Titanium	...	...	Aerated	1	100 (212)	...	0.01 (0.2)	...	90
Titanium	...	...	Aerated	1	100 (212)	...	7 (286)	...	90
Titanium	...	...	Aerated	3	60 (140)	...	0.01 (0.5)	...	90
Titanium	...	...	Aerated	3	100 (212)	...	23 (936)	...	90
Titanium	...	...	Aerated	3	100 (212)	...	21 (844)	...	90
Titanium	...	...	Aerated	5	60 (140)	...	5 (193)	...	90
Titanium	...	...	Aerated	10	35 (95)	...	1.3 (51)	...	90
Titanium	...	...	Aerated	40	35 (95)	...	9 (345)	...	90
Titanium	...	...	Aerated	75	35 (95)	...	1.1 (1.0)	...	90
Titanium	...	...	Aerated	75	Room	...	11 (432)	...	90
Titanium	...	...	Aerated	Conc	Room	...	1.6 (63)	...	90
Titanium	...	...	Aerated	Conc	Boiling	...	5 (215)	...	90
Titanium	...	...	Plus 0.25% $CuSO_4$	5	95 (204)	...	Resistant	...	90
Titanium	...	...	Plus 0.25% $CuSO_4$	30	38 (100)	...	0.06 (2.4)	...	90
Titanium	...	...	Plus 0.25% $CuSO_4$	30	95 (204)	...	0.09 (3.5)	...	90
Titanium	...	...	Plus 0.5% CrO_3	5	95 (204)	...	Resistant	...	90
Titanium	...	...	Plus 0.5% $CuSO_4$	30	38 (100)	...	0.07 (2.7)	...	90
Titanium	...	...	Plus 0.5% $CuSO_4$	30	95 (204)	...	0.8 (33)	...	90
Titanium	...	...	Plus 0.5% $CuSO_4$	30	95 (204)	...	Resistant	...	90
Titanium	...	...	Plus 1.0% $CuSO_4$	30	38 (100)	...	0.02 (0.8)	...	90
Titanium	...	...	Plus 1.0% $CuSO_4$	30	95 (204)	...	0.9 (35)	...	90

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium	...	...	Plus 1.0% $CuSO_4$	30	Boiling	...	1.7 (66)	...	90
Titanium	...	...	Plus 10% HNO_3	90	Room	...	0.5 (18)	...	90
Titanium	...	...	Plus 20% HNO_3	80	60 (140)	...	1.6 (64)	...	90
Titanium	...	...	Plus 4 g/L Ti^{4+}	40	100 (212)	...	Resistant	...	90
Titanium	...	...	Plus 50% HNO_3	50	60 (140)	...	0.4 (16)	...	90
Titanium	...	...	Plus 50% HNO_3	50	Room	...	0.6 (25)	...	90
Titanium	...	...	Plus 70% HNO_3	30	Room	...	0.1 (4.1)	...	90
Titanium	...	...	Plus 90% HNO_3	10	Room	...	Resistant	...	90
Titanium	...	...	Plus 90% HNO_3	10	60 (140)	...	0.01 (0.4)	...	90
Titanium	...	...	Plus 95% HNO_3	5	60 (140)	...	0.005 (0.2)	...	90
Titanium	...	...	Saturated with chlorine	5	190 (374)	...	0.025 (1) max	...	90
Titanium	...	...	Saturated with chlorine	10	190 (374)	...	0.025 (1) max	...	90
Titanium	...	...	Saturated with chlorine	45	24 (75)	...	0.003 (0.1)	...	90
Titanium	...	...	Saturated with chlorine	62	16 (61)	...	0.003 (0.1)	...	90
Titanium	...	...	Saturated with chlorine	82	50 (122)	...	1.2 (48) min	...	90
Titanium	...	...	Vapors	96	38 (100)	...	Resistant	...	90
Titanium	...	...	Vapors	96	66 (151)	...	Resistant	...	90
Titanium	...	...	Vapors	96	200-300 (392-572)	...	0.01 (0.5)	...	90
Titanium + 0.4Pd	...	...	...	1	Boiling	24 h	0.05 (2) max	...	245
Titanium + 0.54Pt	...	...	...	1	Boiling	24 h	0.05 (2) max	...	245
Titanium, grade 12	R53400	...	Naturally aerated	0.75	Boiling	...	0.003 (0.1)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	1.0	Boiling	...	0.9 (36)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	1.0	204 (400)	...	0.9 (36)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	2.75	66 (150)	...	0.02 (0.6)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	3.0	66 (150)	...	1.7 (65)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	3.5	52 (125)	...	0.01 (0.5)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	3.75	52 (125)	...	1.7 (68)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	9	24 (75)	...	0.003 (0.1)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	9.5	24 (75)	...	0.01 (0.2)	...	33
Titanium, grade 12	R53400	...	Naturally aerated	10	24 (75)	...	0.4 (15)	...	33
Titanium, grade 12	R53400	...	Plus 100 ppm Cu^{2+}, 1% thiourea (deaerated)	1	100 (212)	...	0.2 (9)	...	33
Titanium, grade 7	R52400	...	Aerated	10	70 (158)	...	0.10 (3.9)	...	33
Titanium, grade 7	R52400	...	Aerated	40	70 (158)	...	0.9 (37)	...	33
Titanium, grade 7	R52400	...	Chlorine saturated	10	190 (375)	...	0.051 (2.0)	...	33
Titanium, grade 7	R52400	...	Chlorine saturated	20	190 (375)	...	0.4 (39)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	1.0	204 (400)	...	0.005 (0.2)	...	33
Titanium, grade 7	R52400	...	Naturally aerated	2.0	204 (400)	...	Resistant	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	1	190 (375)	...	0.1 (5)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	5	190 (375)	...	0.1 (5)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	5	70 (158)	...	0.15 (5.9)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	10	190 (375)	...	1.5 (59)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	10	25 (75)	...	0.025 (1.0)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	10	70 (158)	...	0.25 (10)	...	33
Titanium, grade 7	R52400	...	Nitrogen saturated	40	25 (75)	...	0.2 (9)	...	33
Titanium, grade 7	R52400	...	Oxygen saturated	1-10	190 (375)	...	0.1 (5)	...	33
Titanium, grade 7	R52400	...	Plus 1% $CuSO_4$	30	Boiling	...	1.8 (69)	...	33
Titanium, grade 7	R52400	...	Plus 100 ppm Cu^{2+}, 1% thiourea (deaerated)	1	100 (212)	...	Resistant	...	33
Titanium, grade 7	R52400	...	Plus 1000 ppm Cl^-	15	49 (120)	...	0.015 (0.6)	...	33
Titanium, grade 7	R52400	...	Plus 15% $CuSO_4$	15	Boiling	...	0.6 (25)	...	33
Titanium, grade 7	R52400	...	Plus 16 g/L $Fe_2(SO_4)_3$	10	Boiling	...	0.03 (1.2) max	...	33
Titanium, grade 7	R52400	...	Plus 16 g/L $Fe_2(SO_4)_3$	20	Boiling	...	0.15 (6)	...	33

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Titanium, grade 7	R52400	...	Plus 5 g/L $Fe_2(SO_4)_3$	10	Boiling	...	0.2 (7)	...	33
Titanium, grade 9	...	...	Aerated	5	35 (95)	...	0.03 (1.0)	...	33
Titanium, grade 9	...	...	Naturally aerated	0.5	Boiling	...	8 (334)	...	33
Titanium, grade 9	...	...	Nitrogen saturated	5	35 (95)	...	0.4 (16)	...	33
Stainless steels									
18-8 PLUS	S31600	Annealed	Average of three 48-h test periods	5	80 (176)	48 h	0.0508 (2)	...	145
18-8 PLUS	S31600	Annealed	Average of three 48-h test periods	10	80 (176)	48 h	0.0508 (2)	...	145
18Cr-2Ni-12Mn	S24100	...	Average of three 48-h test periods	5	80 (176)	48 h	6.299 (248)	...	145
18Cr-2Ni-12Mn	S24100	Annealed	Average of three 48-h test periods	20	93 (200)	48 h	0.038 (1.5)	...	145
18Cr-2Ni-12Mn	S24100	...	Passive in 2nd and 3rd periods. Average of three 48-h test periods	5 wt%	80 (176)	48 h	6 (248)	...	47
20 Cb-3	N08020	...	...	10	Boiling	...	1.28 (51)	...	212
20 Cb-3	N08020	...	...	60	Boiling	...	1.95 (78)	...	212
20 Cb-3	N08020	...	...	56	Boiling	...	0.25 (10)	...	212
20Cb-3	N08020	...	...	10	Boiling	...	1.08 (43)	...	219
21Cr-6Ni-9Mn	S21900	Annealed	Five 48-h test periods	5	Room	48 h	Resistant	...	47
22Cr-13Ni-5Mn	S20910	Annealed	Average of three 48-h test periods	5	80 (176)	48 h	0.005 (0.2)	...	145
22Cr-13Ni-5Mn	S20910	Annealed	Average of three 48-h test periods	10	80 (176)	48 h	0.381 (15)	...	145
29Cr-4Mo	S44700	...	...	10	Boiling	...	1.25 (4.8)	...	245
29Cr-4Mo	S44700	...	Alloy contains 0.2% Pd	10	Boiling	...	.03 (1)	...	245
29Cr-4Mo	S44700	...	Alloy contains 0.2% Pt	10	Boiling	...	.03 (50)	...	245
29Cr-4Mo	S44700	...	Alloy contains 0.2% Ru	10	Boiling	...	.23 (1)	...	245
301	S30100	...	...	...	Boiling	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Questionable	...	253
301	S30100	...	...	1	20 (68)	...	Good	...	253
301	S30100	...	...	1	70 (158)	...	Good	...	253
301	S30100	...	...	1	Boiling	...	Good	...	253
301	S30100	...	...	2.5	20 (68)	...	Good	...	253
301	S30100	...	...	2.5	70 (158)	...	Good	...	253
301	S30100	...	...	2.5	Boiling	...	Questionable	...	253
301	S30100	...	...	5	20 (68)	...	Good	...	253
301	S30100	...	...	5	70 (158)	...	Good	...	253
301	S30100	...	...	5	Boiling	...	Poor	...	253
301	S30100	...	...	7.5	20 (68)	...	Good	...	253
301	S30100	...	...	7.5	70 (158)	...	Good	...	253
301	S30100	...	...	7.5	Boiling	...	Questionable	...	253
301	S30100	...	...	10	20 (68)	...	Questionable	...	253
301	S30100	...	...	10	70 (158)	...	Questionable	...	253
301	S30100	...	...	10	Boiling	...	Poor	...	253
301	S30100	...	...	20	20 (68)	...	Good	...	253
301	S30100	...	...	20	70 (158)	...	Questionable	...	253
301	S30100	...	...	20	Boiling	...	Poor	...	253
301	S30100	...	...	40	20 (68)	...	Good	...	253
301	S30100	...	...	40	70 (158)	...	Questionable	...	253
301	S30100	...	...	40	Boiling	...	Poor	...	253
301	S30100	...	...	60	20 (68)	...	Poor	...	253
301	S30100	...	...	60	70 (158)	...	Poor	...	253
301	S30100	...	...	60	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
301	S30100	...	...	80	20 (68)	...	Good	...	253
301	S30100	...	...	80	70 (158)	...	Poor	...	253
301	S30100	...	...	80	Boiling	...	Poor	...	253
301	S30100	...	...	98	20 (68)	...	Resistant	...	253
301	S30100	...	...	98	70 (158)	...	Questionable	...	253
301	S30100	...	...	98	150 (302)	...	Questionable	...	253
301	S30100	...	...	98	Boiling	...	Poor	...	253
301	S30100	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
301	S30100	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
301	S30100	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
301	S30100	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
301	S30100	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
301	S30100	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
301	S30100	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
301	S30100	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
301	S30100	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
301	S30100	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
301	S30100	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
301	S30100	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
301	S30100	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
301	S30100	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
301	S30100	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
301	S30100	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
301	S30100	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
301	S30100	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
301	S30100	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
302	S30200	...	...	...	Boiling	...	Questionable	...	253
302	S30200	...	...	1	20 (68)	...	Good	...	253
302	S30200	...	...	1	70 (158)	...	Good	...	253
302	S30200	...	...	1	Boiling	...	Good	...	253
302	S30200	...	...	2.5	20 (68)	...	Good	...	253
302	S30200	...	...	2.5	70 (158)	...	Good	...	253
302	S30200	...	...	2.5	Boiling	...	Questionable	...	253
302	S30200	...	...	5	20 (68)	...	Good	...	253
302	S30200	...	...	5	70 (158)	...	Good	...	253
302	S30200	...	...	5	Boiling	...	Poor	...	253
302	S30200	...	...	7.5	20 (68)	...	Good	...	253
302	S30200	...	...	7.5	70 (158)	...	Good	...	253
302	S30200	...	...	7.5	Boiling	...	Questionable	...	253
302	S30200	...	...	10	20 (68)	...	Questionable	...	253
302	S30200	...	...	10	70 (158)	...	Questionable	...	253
302	S30200	...	...	10	Boiling	...	Poor	...	253
302	S30200	...	...	20	20 (68)	...	Good	...	253
302	S30200	...	...	20	70 (158)	...	Questionable	...	253
302	S30200	...	...	20	Boiling	...	Poor	...	253
302	S30200	...	...	40	20 (68)	...	Good	...	253
302	S30200	...	...	40	70 (158)	...	Questionable	...	253
302	S30200	...	...	40	Boiling	...	Poor	...	253
302	S30200	...	...	60	20 (68)	...	Poor	...	253
302	S30200	...	...	60	70 (158)	...	Poor	...	253
302	S30200	...	...	60	Boiling	...	Poor	...	253
302	S30200	...	...	80	20 (68)	...	Good	...	253
302	S30200	...	...	80	70 (158)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	80	Boiling	...	Poor	...	253
302	S30200	...	...	98	20 (68)	...	Resistant	...	253
302	S30200	...	...	98	70 (158)	...	Questionable	...	253
302	S30200	...	...	98	150 (302)	...	Questionable	...	253
302	S30200	...	...	98	Boiling	...	Poor	...	253
302	S30200	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
302	S30200	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
302	S30200	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
302	S30200	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
302	S30200	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
302	S30200	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
302	S30200	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
302	S30200	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
302	S30200	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
302	S30200	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
302	S30200	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
302	S30200	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
302	S30200	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
302	S30200	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
302	S30200	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
302	S30200	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
302	S30200	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
302	S30200	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
302	S30200	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
303	S30300	...	...	...	Boiling	...	Questionable	...	253
303	S30300	...	...	1	20 (68)	...	Good	...	253
303	S30300	...	...	1	70 (158)	...	Good	...	253
303	S30300	...	...	1	Boiling	...	Good	...	253
303	S30300	...	...	2.5	20 (68)	...	Good	...	253
303	S30300	...	...	2.5	70 (158)	...	Good	...	253
303	S30300	...	...	2.5	Boiling	...	Poor	...	253
303	S30300	...	...	5	20 (68)	...	Poor	...	253
303	S30300	...	...	5	20 (68)	...	Good	...	253
303	S30300	...	...	5	70 (158)	...	Good	...	253
303	S30300	...	...	5	Boiling	...	Poor	...	253
303	S30300	...	...	7.5	20 (68)	...	Good	...	253
303	S30300	...	...	7.5	70 (158)	...	Good	...	253
303	S30300	...	...	7.5	Boiling	...	Questionable	...	253
303	S30300	...	...	10	20 (68)	...	Questionable	...	253
303	S30300	...	...	10	70 (158)	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Poor	...	253
303	S30300	...	...	20	20 (68)	...	Good	...	253
303	S30300	...	...	20	70 (158)	...	Questionable	...	253
303	S30300	...	...	20	Boiling	...	Poor	...	253
303	S30300	...	...	40	20 (68)	...	Good	...	253
303	S30300	...	...	40	70 (158)	...	Questionable	...	253
303	S30300	...	...	40	Boiling	...	Poor	...	253
303	S30300	...	...	60	20 (68)	...	Poor	...	253
303	S30300	...	...	60	70 (158)	...	Poor	...	253
303	S30300	...	...	60	Boiling	...	Poor	...	253
303	S30300	...	...	80	20 (68)	...	Poor	...	253
303	S30300	...	...	80	70 (158)	...	Poor	...	253
303	S30300	...	...	80	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	98	20 (68)	...	Resistant	...	253
303	S30300	...	...	98	70 (158)	...	Questionable	...	253
303	S30300	...	...	98	150 (302)	...	Questionable	...	253
303	S30300	...	...	98	Boiling	...	Poor	...	253
303	S30300	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
303	S30300	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
303	S30300	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
303	S30300	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
303	S30300	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
303	S30300	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
303	S30300	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
303	S30300	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
303	S30300	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
303	S30300	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
303	S30300	...	Plus 25% HNO_3	75	50 (122)	...	Questionable	...	253
303	S30300	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
303	S30300	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
303	S30300	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
303	S30300	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
303	S30300	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
303	S30300	...	Plus 50% HNO_3	50	50 (122)	...	Questionable	...	253
303	S30300	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
303	S30300	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
303	S30300	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
304	S30400	...	...	0.25	60 (140)	1 d	0.9 (36)	...	89
304	S30400	...	...	0.5	40 (104)	1 d	0.6 (25)	...	89
304	S30400	...	...	0.5	60 (140)	1 d	1.2 (47)	...	89
304	S30400	...	...	1	Room	1 d	0.6 (25)	...	89
304	S30400	...	...	1	40 (104)	1 d	0.7 (28)	...	89
304	S30400	...	...	1	60 (140)	1 d	Resistant	...	89
304	S30400	...	...	2.5	Room	1 d	0.8 (31)	...	89
304	S30400	...	...	2.5	40 (104)	1 d	0.9 (36)	...	89
304	S30400	...	...	2.5	60 (140)	1 d	4 (160)	...	89
304	S30400	...	...	5	Room	1 d	1.2 (47)	...	89
304	S30400	...	...	5	40 (104)	1 d	1.5 (58)	...	89
304	S30400	...	...	10	Boiling	...	12 (500) min	...	89
304	S30400	...	...	10	Room	1 d	1.6 (65)	...	89
304	S30400	...	...	10	40 (104)	1 d	4 (170)	...	89
304	S30400	...	...	20	Room	1 d	3 (130)	...	89
304	S30400	...	...	20	40 (104)	1 d	17 (680)	...	89
304	S30400	...	...	35	Room	1 d	15 (600)	...	89
304	S30400	...	...	95	30 (86)	...	0.28 (11)	...	120
304	S30400	...	...	10	Boiling	...	410 (16400)	...	219
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Questionable	...	253
304	S30400	...	...	1	20 (68)	...	Good	...	253
304	S30400	...	...	1	70 (158)	...	Good	...	253
304	S30400	...	...	1	Boiling	...	Good	...	253
304	S30400	...	...	2.5	20 (68)	...	Good	...	253
304	S30400	...	...	2.5	70 (158)	...	Good	...	253
304	S30400	...	...	2.5	Boiling	...	Questionable	...	253
304	S30400	...	...	5	20 (68)	...	Good	...	253
304	S30400	...	...	5	70 (158)	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	5	Boiling	...	Poor	...	253
304	S30400	...	...	7.5	20 (68)	...	Good	...	253
304	S30400	...	...	7.5	70 (158)	...	Good	...	253
304	S30400	...	...	7.5	Boiling	...	Questionable	...	253
304	S30400	...	...	10	20 (68)	...	Questionable	...	253
304	S30400	...	...	10	70 (158)	...	Questionable	...	253
304	S30400	...	...	10	Boiling	...	Poor	...	253
304	S30400	...	...	20	20 (68)	...	Good	...	253
304	S30400	...	...	20	70 (158)	...	Questionable	...	253
304	S30400	...	...	20	Boiling	...	Poor	...	253
304	S30400	...	...	40	20 (68)	...	Good	...	253
304	S30400	...	...	40	70 (158)	...	Questionable	...	253
304	S30400	...	...	40	Boiling	...	Poor	...	253
304	S30400	...	...	60	20 (68)	...	Poor	...	253
304	S30400	...	...	60	70 (158)	...	Poor	...	253
304	S30400	...	...	60	Boiling	...	Poor	...	253
304	S30400	...	...	80	20 (68)	...	Good	...	253
304	S30400	...	...	80	70 (158)	...	Poor	...	253
304	S30400	...	...	80	Boiling	...	Poor	...	253
304	S30400	...	...	98	20 (68)	...	Resistant	...	253
304	S30400	...	...	98	70 (158)	...	Questionable	...	253
304	S30400	...	...	98	150 (302)	...	Questionable	...	253
304	S30400	...	...	98	Boiling	...	Poor	...	253
304	S30400	Annealed	Average of three 48-h test periods	20	93 (200)	48 h	0.028 (1.1)	...	145
304	S30400	...	Coal by-product processing; slight to moderate aeration; rapid agitation	15	15-30 (59-86)	212 d	0.6 (24)	Severe pitting	89
304	S30400	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
304	S30400	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
304	S30400	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
304	S30400	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
304	S30400	...	Lab test.	8.7	80 (176)	10 d	12 (460)	...	89
304	S30400	...	Lab test; no aeration; no agitation	...	Boiling	...	410 (16500)	...	89
304	S30400	...	Lab test; no aeration; no agitation	10	Boiling	...	410 (16500)	...	89
304	S30400	...	Lab test; no aeration; no agitation	50	32 (90)	...	5 (217)	...	89
304	S30400	...	Lab test; no aeration; no agitation	66	32 (90)	...	5 (204)	...	89
304	S30400	...	Lab test; no aeration; no agitation	77.6	32 (90)	...	0.003 (0.1)	...	89
304	S30400	...	Lab test; rapid agitation	1	Boiling	0.5 d	8 (316)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	0.5	38 (100)	0.08 d	0.9 (37)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	0.5	66 (150)	0.08 d	0.6 (23)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	0.5	79 (175)	0.08 d	11 (445)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	0.5	93 (200)	0.08 d	20 (790)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	1	38 (100)	0.08 d	1.5 (58)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	1	66 (150)	0.08 d	5.5 (220)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Lab test; slight to moderate aeration; no agitation	1	79 (175)	0.08 d	9.5 (380)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	1	93 (200)	0.08 d	20 (790)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	3	38 (100)	0.08 d	1.7 (67)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	3	66 (150)	0.08 d	10 (388)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	3	79 (175)	0.08 d	13 (528)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	3	93 (200)	0.08 d	33 (1300)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	5	38 (100)	0.08 d	6 (222)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	5	66 (150)	0.08 d	28 (1100)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	5	79 (175)	0.08 d	41 (1630)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	5	93 (200)	0.08 d	135 (5400)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	10	38 (100)	0.08 d	10 (390)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	10	65 (150)	0.08 d	45 (1830)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	10	79 (175)	0.08 d	113 (4500)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	10	93 (200)	0.08 d	175 (7000)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	20	65 (150)	0.08 d	1400 (57500)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	20	80 (175)	0.08 d	270 (10700)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	20	93 (200)	0.08 d	525 (21000)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	20	38 (100)	0.08 d	25 (1010)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	40	38 (100)	0.08 d	21 (850)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	40	65 (150)	0.08 d	325 (13000)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	80	38 (100)	0.08 d	18 (736)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	80	65 (150)	0.08 d	315 (12600)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	80	79 (175)	0.08 d	53 (2100)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	80	93 (200)	0.08 d	175 (7050)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	95	38 (100)	0.08 d	0.1 (4)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	95	65 (150)	0.08 d	4 (150)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	95	79 (175)	0.08 d	3 (138)	...	89
304	S30400	...	Lab test; slight to moderate aeration; no agitation	95	93 (200)	0.08 d	4 (177)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	5	16 (60)	1 d	0.3 (13)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	5	40 (104)	1 d	2.2 (88)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	10	15 (60)	1 d	0.5 (18)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Lab test; strong aeration; no agitation	10	40 (104)	1 d	5 (193)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	15	15 (60)	1 d	0.8 (30)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	15	40 (104)	1 d	7 (292)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	20	15 (60)	1 d	11 (440)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	20	40 (104)	1 d	11 (437)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	25	15 (60)	1 d	1.3 (53)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	25	40 (104)	1 d	10 (410)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	30	15 (60)	1 d	0.9 (35)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	30	40 (104)	1 d	12 (474)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	40	15 (60)	1 d	1.2 (48)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	40	40 (104)	1 d	23 (900)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	50	15 (50)	1 d	4 (150)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	50	40 (104)	1 d	110 (4400)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	60	15 (60)	1 d	8 (306)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	60	40 (104)	1 d	9 (346)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	70	15 (60)	1 d	1.0 (39)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	70	40 (104)	1 d	2.2 (88)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	80	15 (60)	60 d	0.05 (2)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	80	40 (104)	1 d	0.6 (22)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	90	40 (104)	1 d	0.4 (17)	...	89
304	S30400	...	Lab test; strong aeration; no agitation	95	40 (104)	1 d	0.6 (22)	...	89
304	S30400	...	Metal (cleaning) processing; strong aeration; rapid agitation	30	54 (130)	62 d	0.003 (0.1)	...	89
304	S30400	...	Metal (pickling) processing; no aeration; no agitaio	8	54 (130)	47 d	0.3 (11)	...	89
304	S30400	...	Metal (pickling) processing; no aeration; no agitation.	8	54 (130)	47 d	1.3 (50)	...	89
304	S30400	...	Metal (pickling) processing; strong aeration; rapid agitation	~12	85-90 (185-195)	14 d	0.3 (13)	Slight pitting	89
304	S30400	...	Passive in 2nd and 3rd periods. Annealed. Average of three 48-h test periods	5 wt%	80 (176)	48 h	2.1 (85)	...	47
304	S30400	Annealed	Passive in 2nd and 3rd periods. Average of three 48-h test periods	5	80 (176)	48 h	2 (85)	...	145
304	S30400	...	Plastic processing; no aeration; no agitation.	93.5	9-25 (49-77)	102 d	.003 (0.1) max	...	89
304	S30400	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
304	S30400	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
304	S30400	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
304	S30400	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
304	S30400	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
304	S30400	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
304	S30400	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
304	S30400	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
304	S30400	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
304	S30400	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
304	S30400	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
304	S30400	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
304	S30400	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
304	S30400	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
304	S30400	...	Pulp and paper processing	~2	...	90 d	Resistant	...	89
304	S30400	...	Strong aeration; no agitation	~20	40 (104) max	8.5 d	0.005 (0.2)	...	89
304	S30400	...	Strong aeration; no agitation	~20	40 (104) max	8.5 d	0.003 (0.1)	...	89
304	S30400	...	Sugar processing	~10	20-67 (68-152)	97 d	0.003 (0.1) max	...	89
304	S30400	...	Sugar processing	~10	20-67 (68-152)	97 d	0.003 (0.1)	...	89
304	S30400	...	Sugar processing. With carbon over the standard maximum	~10	20-67 (68-152)	97 d	0.003 (0.1) max	...	89
304	S30400	...	Synthetic rubber processing; strong aeration; slight to moderate agitation	0.5	27-43 (80-110)	9 d	0.5 (21)	...	89
304	S30400	...	Synthetic rubber processing; strong aeration; slight to moderate agitation. With carbon over the standard maximum	0.5	27-43 (80-110)	9 d	0.1 (5.6)	...	89
304	S30400	...	Textile processing; slight to moderate aeration; slight to moderate agitatio	5	27 (80)	106 d	Resistant	...	89
304	S30400	...	Textile processing; strong aeration; no agitation	5	Room	104 d	0.003 (0.1) max	...	89
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Questionable	...	253
304L	S30403	...	...	1	20 (68)	...	Good	...	253
304L	S30403	...	...	1	70 (158)	...	Good	...	253
304L	S30403	...	...	1	Boiling	...	Good	...	253
304L	S30403	...	...	2.5	20 (68)	...	Good	...	253
304L	S30403	...	...	2.5	70 (158)	...	Good	...	253
304L	S30403	...	...	2.5	Boiling	...	Questionable	...	253
304L	S30403	...	...	5	20 (68)	...	Good	...	253
304L	S30403	...	...	5	70 (158)	...	Good	...	253
304L	S30403	...	...	5	Boiling	...	Poor	...	253
304L	S30403	...	...	7.5	20 (68)	...	Good	...	253
304L	S30403	...	...	7.5	70 (158)	...	Good	...	253
304L	S30403	...	...	7.5	Boiling	...	Questionable	...	253
304L	S30403	...	...	10	20 (68)	...	Questionable	...	253
304L	S30403	...	...	10	70 (158)	...	Questionable	...	253
304L	S30403	...	...	10	Boiling	...	Poor	...	253
304L	S30403	...	...	20	20 (68)	...	Good	...	253
304L	S30403	...	...	20	70 (158)	...	Questionable	...	253
304L	S30403	...	...	20	Boiling	...	Poor	...	253
304L	S30403	...	...	40	20 (68)	...	Good	...	253
304L	S30403	...	...	40	70 (158)	...	Questionable	...	253
304L	S30403	...	...	40	Boiling	...	Poor	...	253
304L	S30403	...	...	60	20 (68)	...	Poor	...	253
304L	S30403	...	...	60	70 (158)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304L	S30403	...	...	60	Boiling	...	Poor	...	253
304L	S30403	...	...	80	20 (68)	...	Good	...	253
304L	S30403	...	...	80	70 (158)	...	Poor	...	253
304L	S30403	...	...	80	Boiling	...	Poor	...	253
304L	S30403	...	...	98	20 (68)	...	Resistant	...	253
304L	S30403	...	...	98	70 (158)	...	Questionable	...	253
304L	S30403	...	...	98	150 (302)	...	Questionable	...	253
304L	S30403	...	...	98	Boiling	...	Poor	...	253
304L	S30403	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
304L	S30403	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
304L	S30403	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
304L	S30403	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
304L	S30403	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
304L	S30403	...	Plus 10% HNO_3	70	168 (3347)	...	Poor	...	253
304L	S30403	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
304L	S30403	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
304L	S30403	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
304L	S30403	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
304L	S30403	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
304L	S30403	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
304L	S30403	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
304L	S30403	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
304L	S30403	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
304L	S30403	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
304L	S30403	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Questionable	...	253
304LN	S30453	...	...	1	20 (68)	...	Good	...	253
304LN	S30453	...	...	1	70 (158)	...	Good	...	253
304LN	S30453	...	...	1	Boiling	...	Good	...	253
304LN	S30453	...	...	2.5	20 (68)	...	Good	...	253
304LN	S30453	...	...	2.5	70 (158)	...	Good	...	253
304LN	S30453	...	...	2.5	Boiling	...	Questionable	...	253
304LN	S30453	...	...	5	20 (68)	...	Good	...	253
304LN	S30453	...	...	5	70 (158)	...	Good	...	253
304LN	S30453	...	...	5	Boiling	...	Poor	...	253
304LN	S30453	...	...	7.5	20 (68)	...	Good	...	253
304LN	S30453	...	...	7.5	70 (158)	...	Good	...	253
304LN	S30453	...	...	7.5	Boiling	...	Questionable	...	253
304LN	S30453	...	...	10	20 (68)	...	Questionable	...	253
304LN	S30453	...	...	10	70 (158)	...	Questionable	...	253
304LN	S30453	...	...	10	Boiling	...	Poor	...	253
304LN	S30453	...	...	20	20 (68)	...	Good	...	253
304LN	S30453	...	...	20	70 (158)	...	Questionable	...	253
304LN	S30453	...	...	20	Boiling	...	Poor	...	253
304LN	S30453	...	...	40	20 (68)	...	Good	...	253
304LN	S30453	...	...	40	70 (158)	...	Questionable	...	253
304LN	S30453	...	...	40	Boiling	...	Poor	...	253
304LN	S30453	...	...	60	20 (68)	...	Poor	...	253
304LN	S30453	...	...	60	70 (158)	...	Poor	...	253
304LN	S30453	...	...	60	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304LN	S30453	...	...	80	20 (68)	...	Good	...	253
304LN	S30453	...	...	80	70 (158)	...	Poor	...	253
304LN	S30453	...	...	80	Boiling	...	Poor	...	253
304LN	S30453	...	...	98	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	98	70 (158)	...	Questionable	...	253
304LN	S30453	...	...	98	150 (302)	...	Questionable	...	253
304LN	S30453	...	...	98	Boiling	...	Poor	...	253
304LN	S30453	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
304LN	S30453	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
304LN	S30453	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
304LN	S30453	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
304LN	S30453	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
304LN	S30453	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
304LN	S30453	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
304LN	S30453	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
304LN	S30453	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
304LN	S30453	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
304LN	S30453	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
304LN	S30453	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
304LN	S30453	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
304LN	S30453	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
304LN	S30453	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
304LN	S30453	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
304LN	S30453	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
316	S31600	...	...	0.25	Boiling	1 d	0.07 (2.7)	...	89
316	S31600	...	...	.25	60 (140)	1 d	Resistant	...	89
316	S31600	...	...	.25	80 (176)	1 d	Resistant	...	89
316	S31600	...	...	0.5	40 (104)	1 d	Resistant	...	89
316	S31600	...	...	0.5	60 (140)	1 d	Resistant	...	89
316	S31600	...	...	0.5	80 (176)	1 d	Resistant	...	89
316	S31600	...	...	0.5	Boiling	1 d	1.4 (54)	...	89
316	S31600	...	...	1	Room	1 d	Resistant	...	89
316	S31600	...	...	1	40 (104)	1 d	Resistant	...	89
316	S31600	...	...	1	60 (140)	1 d	Resistant	...	89
316	S31600	...	...	1	80 (176)	1 d	Resistant	...	89
316	S31600	...	...	1	Boiling	1 d	3.5 (140)	...	89
316	S31600	...	...	2.5	Room	1 d	Resistant	...	89
316	S31600	...	...	2.5	40 (104)	1 d	Resistant	...	89
316	S31600	...	...	2.5	60 (140)	1 d	0.1 (3.6)	...	89
316	S31600	...	...	2.5	80 (176)	1 d	1.0 (36)	...	89
316	S31600	...	...	5	Room	1 d	Resistant	...	89
316	S31600	...	...	5	40 (104)	1 d	Resistant	...	89
316	S31600	...	...	10	40 (104)	1 d	0.1 (3.6)	...	89
316	S31600	...	...	10	Room	1 d	Resistant	...	89
316	S31600	...	...	10	80 (176)	1 d	5 (180)	...	89
316	S31600	...	...	10	Boiling	...	5 (200) min	...	89
316	S31600	...	...	10	Boiling	...	9 (372)	...	120
316	S31600	Welded	...	10	Boiling	...	9 (371)	...	120
316	S31600	...	...	20	40 (104)	1 d	0.7 (27)	...	89
316	S31600	...	...	20	Room	1 d	0.2 (9)	...	89
316	S31600	...	...	35	Room	1 d	1.8 (72)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	10	Boiling	...	21 (855)	...	219
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Good	...	253
316	S31600	...	...	1	20 (68)	...	Resistant	...	253
316	S31600	...	...	1	70 (158)	...	Resistant	...	253
316	S31600	...	...	1	Boiling	...	Good	...	253
316	S31600	...	...	2.5	20 (68)	...	Resistant	...	253
316	S31600	...	...	2.5	70 (158)	...	Resistant	...	253
316	S31600	...	...	2.5	Boiling	...	Questionable	...	253
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316	S31600	...	...	5	70 (158)	...	Good	...	253
316	S31600	...	...	5	Boiling	...	Questionable	...	253
316	S31600	...	...	7.5	20 (68)	...	Resistant	...	253
316	S31600	...	...	7.5	70 (158)	...	Good	...	253
316	S31600	...	...	7.5	Boiling	...	Questionable	...	253
316	S31600	...	...	10	20 (68)	...	Good	...	253
316	S31600	...	...	10	70 (158)	...	Questionable	...	253
316	S31600	...	...	10	Boiling	...	Questionable	...	253
316	S31600	...	...	20	20 (68)	...	Good	...	253
316	S31600	...	...	20	70 (158)	...	Questionable	...	253
316	S31600	...	...	20	Boiling	...	Poor	...	253
316	S31600	...	...	40	20 (68)	...	Good	...	253
316	S31600	...	...	40	70 (158)	...	Questionable	...	253
316	S31600	...	...	40	Boiling	...	Poor	...	253
316	S31600	...	...	60	20 (68)	...	Questionable	...	253
316	S31600	...	...	60	70 (158)	...	Poor	...	253
316	S31600	...	...	60	Boiling	...	Poor	...	253
316	S31600	...	...	80	20 (68)	...	Good	...	253
316	S31600	...	...	80	70 (158)	...	Questionable	...	253
316	S31600	...	...	80	Boiling	...	Poor	...	253
316	S31600	...	...	98	20 (68)	...	Resistant	...	253
316	S31600	...	...	98	70 (158)	...	Questionable	...	253
316	S31600	...	...	98	150 (302)	...	Questionable	...	253
316	S31600	...	...	98	Boiling	...	Poor	...	253
316	S31600	...	0.057% HCl, pH 2 to 5, incineration of municipal waste	0.19	60 (140)	2360 h	0.05 (2) max	...	68
316	S31600	...	1*N*	...	Boiling	...	65 (2600)	...	51
316	S31600	...	3% chromic acid in deionized water	10	80 (175)	...	0.25 (10) max	...	145
316	S31600	...	3% chromic acid in deionized water	10	80-82 (175-180)	...	0.05 (2) max	...	68
316	S31600	...	Activated	1	Boiling	...	.660 (25.8)	...	223
316	S31600	...	Activated	5	Boiling	...	2.71 (107)	...	223
316	S31600	...	Activated	10	Boiling	...	8.73 (343)	...	223
316	S31600	...	Aeration, lab test	5	58-67 (137-153)	29.5 d	1.27 (50) min	...	68
316	S31600	...	Annealed. Average of three 48-h test periods	5	80 (176)	48 h	0.839 (33)	...	145
316	S31600	Annealed	Average of three 48-h test periods	10	80 (176)	48 h	2.9 (112)	...	98
316	S31600	...	Coal by-product processing; slight to moderate aeration; rapid agitation	15	15-30 (59-86)	212 d	0.4 (14)	...	89
316	S31600	...	Dilute. Activated before tests	1	Boiling	...	0.7 (26)	...	98
316	S31600	...	Dilute. Activated before tests	5	Boiling	...	2.72 (107)	...	98
316	S31600	...	Dilute. Activated before tests	10	Boiling	...	9 (344)	...	98

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Dilute. Activated. Sample activated at start of each test period. Five 48-h test periods	1	Boiling	48 h	0.7 (26)	...	39
316	S31600	...	Dilute. Activated. Sample activated at start of each test period. Five 48-h test periods	5	Boiling	48 h	2.718 (107)	...	39
316	S31600	...	Dilute. Nonactivated. Five 48-h test periods	1	Boiling	48 h	0.6 (22)	...	39
316	S31600	...	Dilute. Nonactivated. Five 48-h test periods	5	Boiling	48 h	2.489 (98)	...	39
316	S31600	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
316	S31600	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
316	S31600	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
316	S31600	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
316	S31600	...	Hot H_2SO_4, pH 3.0, containing W and Mo salts with 2-3 g/L fluorides, moderate aeration	0-4	60 (140)	...	0.25 (10) max	...	68
316	S31600	...	Lab test	8.7	80 (176)	10 d	0.003 (0.1)	...	89
316	S31600	...	Lab test; no aeration; no agitation	10	Boiling	...	22 (860)	...	89
316	S31600	...	Lab test; no aeration; no agitation	10	Boiling	...	22 (860)	...	89
316	S31600	...	Lab test; no aeration; no agitation	10	60 (140)	1 d	2.3 (90)	...	89
316	S31600	...	Lab test; no aeration; no agitation	50	32 (90)	...	Poor	...	89
316	S31600	...	Lab test; no aeration; no agitation	66	32 (90)	...	4 (144)	...	89
316	S31600	...	Lab test; no aeration; no agitation	77.6	32 (90)	...	0.003 (0.1)	...	89
316	S31600	...	Lab test; rapid agitation	1	Boiling	0.5 d	12 (490)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	0.5	38 (100)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	0.5	66 (150)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	0.5	79 (175)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	0.5	93 (200)	0.08 d	0.1 (3.8)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	1	38 (100)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	1	66 (150)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	1	79 (175)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	1	93 (200)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	3	38 (100)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	3	66 (150)	0.08 d	0.2 (8)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	3	79 (175)	0.08 d	1.0 (40)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	3	93 (200)	0.08 d	2.4 (94)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	5	38 (100)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	5	66 (150)	0.08 d	0.9 (36)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	5	79 (175)	0.08 d	19 (740)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Lab test; slight to moderate aeration; no agitation	5	93 (200)	0.08 d	3.5 (140)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	10	65 (150)	0.08 d	2 (81)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	10	38 (100)	0.08 d	0.24 (9.6)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	10	79 (175)	0.08 d	4 (150)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	10	93 (200)	0.08 d	5 (207)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	20	95 (200)	0.08 d	44 (1770)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	20	80 (175)	0.08 d	21 (840)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	20	65 (150)	0.08 d	5 (191)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	20	38 (100)	0.08 d	1.9 (75)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	40	65 (150)	0.08 d	160 (6400)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	40	38 (100)	0.08 d	21 (825)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	80	93 (200)	0.08 d	100 (4000)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	80	79 (175)	0.08 d	30 (1200)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	80	65 (150)	0.08 d	14 (570)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	80	38 (100)	0.08 d	7 (280)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	95	93 (200)	0.08 d	9 (340)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	95	79 (175)	0.08 d	21 (825)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	95	65 (150)	0.08 d	1.5 (59)	...	89
316	S31600	...	Lab test; slight to moderate aeration; no agitation	95	38 (100)	0.08 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	5	40 (104)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	10	40 (104)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	10	15 (60)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	15	40 (104)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	15	15 (60)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	20	40 (104)	1 d	2.8 (110)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	20	15 (60)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	25	40 (104)	1 d	12 (470)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	25	15 (60)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	30	54 (130)	62 d	0.01 (0.3)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	30	40 (104)	1 d	17 (665)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	30	15 (60)	1 d	1.6 (65)	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Lab test; strong aeration; no agitation	40	40 (104)	1 d	163 (6500)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	40	15 (60)	1 d	5 (180)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	50	40 (104)	1 d	160 (6500)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	50	15 (50)	1 d	6 (258)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	60	40 (104)	1 d	27 (1080)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	60	15 (60)	1 d	11 (430)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	70	40 (104)	1 d	14 (540)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	70	15 (60)	1 d	1.3 (50)	...	89
316	S31600	...	Lab test; strong aeration; no agitation	80	40 (104)	1 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	80	15 (60)	60 d	Resistant	...	89
316	S31600	...	Lab test; strong aeration; no agitation	95	40 (104)	1 d	Resistant	...	89
316	S31600	...	Metal (pickling) processing; no aeration; no agitation	8	54 (130)	47 d	0.04 (1.4)	...	89
316	S31600	...	Metal (pickling) processing; no aeration; no agitation; low-carbon grade (0.03% C max)	10	48-71 (120-160)	23 d	Resistant	...	89
316	S31600	...	Metal (pickling) processing; Strong aeration; no agitation	~12	85-90 (185-195)	14 d	0.7 (27)	...	89
316	S31600	...	Nickel sulfide impurities	10	107 (225)	240 h	1.27 (50) min	...	68
316	S31600	...	Not activated	1	Boiling	...	.550 (21.7)	...	223
316	S31600	...	Not activated	5	Boiling	...	2.49 (98.2)	...	223
316	S31600	...	Not activated	10	Boiling	...	8.61 (339)	...	223
316	S31600	...	Plastic processing; no aeration; no agitation	93.5	9-25 (49-77)	102 d	Resistant	...	89
316	S31600	...	Plus 0.45% HCl	1.8	175 (347)	...	2.0 (81)	...	225
316	S31600	...	Plus 0.45% HCl	3.5	175 (347)	...	.58 (23)	...	225
316	S31600	...	Plus 0.45% HCl	6.8	175 (347)	...	3.88 (155)	...	225
316	S31600	...	Plus 0.8-5.3% $AlSO_4$, 0-0.3% $KCr(SO_4)_2$, H_2O, moderate aeration	2.8-9.3	28 (83)	...	0.05 (2) max	...	68
316	S31600	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
316	S31600	...	Plus 1-2% Cu, 7000 oz/ton Ag. 200 oz/ton Au, 0.5% Sb, 0.5% Co, 1.0% 12% Te, 2% Cu. Trace Ag, Au, Sb, Co	20	52 (125)	90 d	0.05 (2) max	...	68
316	S31600	...	Plus 1.3% HCl	5.0	175 (347)	...	12.0 (479)	...	225
316	S31600	...	Plus 1.7% HCl	1.8	175 (347)	...	14.5 (578)	...	225
316	S31600	...	Plus 10% $CuSO_4$, 52 pp. Cl^-. Average Baume 28.7, pH 1	10-20	86 (186)	90 d	0.05 (2) max	...	68
316	S31600	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
316	S31600	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
316	S31600	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
316	S31600	...	Plus 12% CO. Copper refining. Moderate aeration	20	52 (125)	90 d	0.05 (2) max	...	68
316	S31600	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
316	S31600	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
316	S31600	...	Plus 21.5% HNO_3	38.5	Boiling	...	1.43 (57)	...	225
316	S31600	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
316	S31600	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
316	S31600	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
316	S31600	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
316	S31600	...	Plus 26.3% HNO_3	47.1	Boiling	...	1.93 (77)	...	225
316	S31600	...	Plus 3-4% zirconyl sulfate	5	32 (90)	15 d	0.05 (2) max	...	68
316	S31600	...	Plus 41.9% HNO_3	24.9	Boiling	...	1.4 (56)	...	225
316	S31600	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
316	S31600	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
316	S31600	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
316	S31600	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
316	S31600	...	Plus 55.9% HNO_3	12.5	Boiling	...	1.25 (50)	...	225
316	S31600	...	Plus 8% $CuSO_4$, 52 ppm Cl. Copper refining	20	63 (145)	90 d	0.05 (2) max	...	68
316	S31600	...	Plus Cu, 10-60 g/L (40 avg.); Ag, 0-12 g/L (3.5 avg.). Solids consist of precious metals, silica, $PbSO_4$, and a few % or less of Se, Te, As, Sb and Bi	5-150 g/L	71 (160)	...	0.05 (2) max	...	68
316	S31600	...	Pulp and paper processing	~2	...	90 d	Resistant	...	89
316	S31600	...	Reacts with Fe_2O_3 to produce $Fe_2(SO_4)_3$, field test, aeration, moderate agitation, 6 ft/s	10-15	112 (234)	10 d	1.27 (50) min	...	68
316	S31600	...	Research; Lab test; strong aeration; no agitation	5	16 (60)	1 d	Resistant	...	89
316	S31600	...	Saturated with $CuSO_4$. Pickling copper and brass. Aeration, moderate agitation	20	60 (140)	120 d	0.05 (2) max	...	68
316	S31600	...	Saturated with SO_2. Slight aeration	14-16	79 (175)	...	1.27 (50) min	...	68
316	S31600	...	Slight to moderate aeration; slight to moderate agitation	5	27 (80)	106 d	Resistant	...	89
316	S31600	...	Strong aeration; no agitation; low-carbon grade (0.03% C max).	~20	40 (104) max	8.5 d	0.003 (0.1)	...	89
316	S31600	...	Sugar processing	~10	20-67 (68-152)	97 d	0.003 (0.1)	...	89
316	S31600	...	Synthetic rubber processing; strong aeration; slight to moderate agitation	0.5	27-43 (80-110)	9 d	0.03 (1.1)	...	89
316	S31600	...	Textile processing; Strong aeration; no agitation	5	Room	104 d	0.03 (0.1) max	...	89
316	S31600	...	To 5% (final before discarding), 0.09% (original), to 0.54% (final) $FeSO_4$. Inhibited with Activol 359	16	74 (165)	...	0.25 (10) max	...	89
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Questionable	...	253
316F	S31620	...	...	1	20 (68)	...	Good	...	253
316F	S31620	...	...	1	70 (158)	...	Good	...	253
316F	S31620	...	...	1	Boiling	...	Good	...	253
316F	S31620	...	...	2.5	20 (68)	...	Good	...	253
316F	S31620	...	...	2.5	70 (158)	...	Good	...	253
316F	S31620	...	...	2.5	Boiling	...	Questionable	...	253
316F	S31620	...	...	5	20 (68)	...	Good	...	253
316F	S31620	...	...	5	70 (158)	...	Good	...	253
316F	S31620	...	...	5	Boiling	...	Poor	...	253
316F	S31620	...	...	7.5	20 (68)	...	Good	...	253
316F	S31620	...	...	7.5	70 (158)	...	Good	...	253
316F	S31620	...	...	7.5	Boiling	...	Questionable	...	253
316F	S31620	...	...	10	20 (68)	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316F	S31620	...	...	10	70 (158)	...	Questionable	...	253
316F	S31620	...	...	10	Boiling	...	Poor	...	253
316F	S31620	...	...	20	20 (68)	...	Good	...	253
316F	S31620	...	...	20	70 (158)	...	Questionable	...	253
316F	S31620	...	...	20	Boiling	...	Poor	...	253
316F	S31620	...	...	40	20 (68)	...	Good	...	253
316F	S31620	...	...	40	70 (158)	...	Questionable	...	253
316F	S31620	...	...	40	Boiling	...	Poor	...	253
316F	S31620	...	...	60	20 (68)	...	Poor	...	253
316F	S31620	...	...	60	70 (158)	...	Poor	...	253
316F	S31620	...	...	60	Boiling	...	Poor	...	253
316F	S31620	...	...	80	20 (68)	...	Good	...	253
316F	S31620	...	...	80	70 (158)	...	Poor	...	253
316F	S31620	...	...	80	Boiling	...	Poor	...	253
316F	S31620	...	...	98	20 (68)	...	Resistant	...	253
316F	S31620	...	...	98	70 (158)	...	Questionable	...	253
316F	S31620	...	...	98	150 (302)	...	Questionable	...	253
316F	S31620	...	...	98	Boiling	...	Poor	...	253
316F	S31620	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
316F	S31620	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
316F	S31620	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
316F	S31620	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
316F	S31620	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
316F	S31620	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
316F	S31620	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
316F	S31620	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
316F	S31620	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
316F	S31620	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
316F	S31620	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
316F	S31620	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
316F	S31620	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
316F	S31620	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
316F	S31620	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
316F	S31620	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
316F	S31620	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
316L	S31603	...	...	10	Boiling	...	47 (1869)	...	212
316L	S31603	...	...	10	Boiling	...	7.1 (282)	...	212
316L	S31603	...	...	60	Boiling	...	0.95 (38)	...	212
316L	S31603	...	...	99	130 (266)	96 h	1.3 (52)	...	224
316L	S31603	...	...	96	130 (266)	...	1.8 (72)	...	224
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	...	1	20 (68)	...	Resistant	...	253
316L	S31603	...	...	1	70 (158)	...	Resistant	...	253
316L	S31603	...	...	1	Boiling	...	Good	...	253
316L	S31603	...	...	2.5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	2.5	70 (158)	...	Resistant	...	253
316L	S31603	...	...	2.5	Boiling	...	Questionable	...	253
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	70 (158)	...	Good	...	253
316L	S31603	...	...	5	Boiling	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	7.5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	7.5	70 (158)	...	Good	...	253
316L	S31603	...	...	7.5	Boiling	...	Questionable	...	253
316L	S31603	...	...	10	20 (68)	...	Good	...	253
316L	S31603	...	...	10	70 (158)	...	Questionable	...	253
316L	S31603	...	...	10	Boiling	...	Questionable	...	253
316L	S31603	...	...	20	20 (68)	...	Good	...	253
316L	S31603	...	...	20	70 (158)	...	Questionable	...	253
316L	S31603	...	...	20	Boiling	...	Poor	...	253
316L	S31603	...	...	40	20 (68)	...	Good	...	253
316L	S31603	...	...	40	70 (158)	...	Questionable	...	253
316L	S31603	...	...	40	Boiling	...	Poor	...	253
316L	S31603	...	...	60	20 (68)	...	Questionable	...	253
316L	S31603	...	...	60	70 (158)	...	Poor	...	253
316L	S31603	...	...	60	Boiling	...	Poor	...	253
316L	S31603	...	...	80	20 (68)	...	Good	...	253
316L	S31603	...	...	80	70 (158)	...	Questionable	...	253
316L	S31603	...	...	80	Boiling	...	Poor	...	253
316L	S31603	...	...	98	20 (68)	...	Resistant	...	253
316L	S31603	...	...	98	70 (158)	...	Questionable	...	253
316L	S31603	...	...	98	150 (302)	...	Questionable	...	253
316L	S31603	...	...	98	Boiling	...	Poor	...	253
316L	S31603	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
316L	S31603	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
316L	S31603	...	Plus 0.5% $CuCl_2$	10	Boiling	96 h	11.3 (450)	...	224
316L	S31603	...	Plus 0.5% $CuCl_2$	20	Boiling	96 h	8.75 (350)	...	224
316L	S31603	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
316L	S31603	...	Plus 10 ppm nitrate	96	130 (266)	...	2.05 (82)	...	224
316L	S31603	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
316L	S31603	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
316L	S31603	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
316L	S31603	...	Plus 1000 ppm ferric ion	96	130 (266)	...	1.5 (60)	...	224
316L	S31603	...	Plus 1000 ppm nitrate	96	130 (266)	...	0.13 (5.2)	...	224
316L	S31603	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
316L	S31603	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
316L	S31603	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
316L	S31603	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
316L	S31603	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
316L	S31603	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
316L	S31603	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
316L	S31603	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
316L	S31603	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
316L	S31603	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
316L	S31603	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Good	...	253
316LN	S31653	...	...	1	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	1	70 (158)	...	Resistant	...	253
316LN	S31653	...	...	1	Boiling	...	Good	...	253
316LN	S31653	...	...	2.5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	2.5	70 (158)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316LN	S31653	...	...	2.5	Boiling	...	Questionable	...	253
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	70 (158)	...	Good	...	253
316LN	S31653	...	...	5	Boiling	...	Questionable	...	253
316LN	S31653	...	...	7.5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	7.5	70 (158)	...	Good	...	253
316LN	S31653	...	...	7.5	Boiling	...	Questionable	...	253
316LN	S31653	...	...	10	20 (68)	...	Good	...	253
316LN	S31653	...	...	10	70 (158)	...	Questionable	...	253
316LN	S31653	...	...	10	Boiling	...	Questionable	...	253
316LN	S31653	...	...	20	20 (68)	...	Good	...	253
316LN	S31653	...	...	20	70 (158)	...	Questionable	...	253
316LN	S31653	...	...	20	Boiling	...	Poor	...	253
316LN	S31653	...	...	40	20 (68)	...	Good	...	253
316LN	S31653	...	...	40	70 (158)	...	Questionable	...	253
316LN	S31653	...	...	40	Boiling	...	Poor	...	253
316LN	S31653	...	...	60	20 (68)	...	Questionable	...	253
316LN	S31653	...	...	60	70 (158)	...	Poor	...	253
316LN	S31653	...	...	60	Boiling	...	Poor	...	253
316LN	S31653	...	...	80	20 (68)	...	Good	...	253
316LN	S31653	...	...	80	70 (158)	...	Questionable	...	253
316LN	S31653	...	...	80	Boiling	...	Poor	...	253
316LN	S31653	...	...	98	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	98	70 (158)	...	Questionable	...	253
316LN	S31653	...	...	98	150 (302)	...	Questionable	...	253
316LN	S31653	...	...	98	Boiling	...	Poor	...	253
316LN	S31653	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
316LN	S31653	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
316LN	S31653	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
316LN	S31653	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
316LN	S31653	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
316LN	S31653	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
316LN	S31653	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
316LN	S31653	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
316LN	S31653	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
316LN	S31653	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
316LN	S31653	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
316LN	S31653	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
316LN	S31653	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
316LN	S31653	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
316LN	S31653	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
316LN	S31653	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
316LN	S31653	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Good	...	253
316Ti	S31635	...	...	1	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	1	70 (158)	...	Resistant	...	253
316Ti	S31635	...	...	1	Boiling	...	Good	...	253
316Ti	S31635	...	...	2.5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	2.5	70 (158)	...	Resistant	...	253
316Ti	S31635	...	...	2.5	Boiling	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	70 (158)	...	Good	...	253
316Ti	S31635	...	...	5	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	7.5	70 (158)	...	Good	...	253
316Ti	S31635	...	...	7.5	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	10	20 (68)	...	Good	...	253
316Ti	S31635	...	...	10	70 (158)	...	Questionable	...	253
316Ti	S31635	...	...	10	Boiling	...	Questionable	...	253
316Ti	S31635	...	...	20	20 (68)	...	Good	...	253
316Ti	S31635	...	...	20	70 (158)	...	Questionable	...	253
316Ti	S31635	...	...	20	Boiling	...	Poor	...	253
316Ti	S31635	...	...	40	20 (68)	...	Good	...	253
316Ti	S31635	...	...	40	70 (158)	...	Questionable	...	253
316Ti	S31635	...	...	40	Boiling	...	Poor	...	253
316Ti	S31635	...	...	60	20 (68)	...	Questionable	...	253
316Ti	S31635	...	...	60	70 (158)	...	Poor	...	253
316Ti	S31635	...	...	60	Boiling	...	Poor	...	253
316Ti	S31635	...	...	80	20 (68)	...	Good	...	253
316Ti	S31635	...	...	80	70 (158)	...	Questionable	...	253
316Ti	S31635	...	...	80	Boiling	...	Poor	...	253
316Ti	S31635	...	...	98	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	98	70 (158)	...	Questionable	...	253
316Ti	S31635	...	...	98	150 (302)	...	Questionable	...	253
316Ti	S31635	...	...	98	Boiling	...	Poor	...	253
316Ti	S31635	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
316Ti	S31635	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
316Ti	S31635	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
316Ti	S31635	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
316Ti	S31635	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
316Ti	S31635	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
316Ti	S31635	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
316Ti	S31635	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
316Ti	S31635	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
316Ti	S31635	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
316Ti	S31635	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
316Ti	S31635	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
316Ti	S31635	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
316Ti	S31635	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
316Ti	S31635	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
316Ti	S31635	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
316Ti	S31635	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
317	S31700	...	Lab test	8.7	80 (176)	10 d	0.6 (25)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	0.5	38 (100)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	0.5	66 (150)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	0.5	79 (175)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	0.5	93 (200)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	1	38 (100)	0.08 d	Resistant	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317	S31700	...	Lab test; slight to moderate aeration; no agitation	1	66 (150)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	1	79 (175)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	1	93 (200)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	3	38 (100)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	3	66 (150)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	3	79 (175)	0.08 d	1.5 (58)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	3	93 (200)	0.08 d	0.5 (120)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	5	38 (100)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	5	66 (150)	0.08 d	0.1 (3.8)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	5	79 (175)	0.08 d	2.3 (90)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	5	93 (200)	0.08 d	6 (230)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	10	65 (150)	0.08 d	2.0 (78)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	10	38 (100)	0.08 d	Resistant	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	10	79 (175)	0.08 d	4.9 (197)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	10	93 (200)	0.08 d	14 (550)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	20	80 (175)	0.08 d	14 (576)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	20	93 (200)	0.08 d	27 (1060)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	20	65 (150)	0.08 d	5 (198)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	20	38 (100)	0.08 d	0.6 (24)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	40	65 (150)	0.08 d	66 (2640)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	40	38 (100)	0.08 d	6 (220)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	80	93 (200)	0.08 d	150 (6050)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	80	79 (175)	0.08 d	84 (3350)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	80	65 (150)	0.08 d	28 (1120)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	80	38 (100)	0.08 d	14 (579)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	95	93 (200)	0.08 d	14 (550)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	95	79 (175)	0.08 d	7 (260)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	95	65 (150)	0.08 d	2.1 (84)	...	89
317	S31700	...	Lab test; slight to moderate aeration; no agitation	95	38 (100)	0.08 d	Resistant	...	89
317	S31700	...	Metal (cleaning) processing; strong aeration; rapid agitation	30	54 (130)	62 d	0.01 (0.4)	...	89
317	S31700	...	Plastic processing; no aeration; no agitation.	93.5	9-25 (49-77)	102 d	0.003 (0.1) max	...	89

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	...	5	66 (150)	...	Resistant	...	63
317L	S31703	...	...	5	Boiling	...	5.1 (200)	...	63
317L	S31703	...	...	10	66 (150)	...	0.2 (9)	...	63
317L	S31703	...	...	10	Boiling	...	12 (490)	...	63
317L	S31703	...	...	20	66 (150)	...	1.3 (50)	...	63
317L	S31703	...	...	10	66 (150)	...	.22 (8.9)	...	219
317L	S31703	...	...	10	Boiling	...	12.3 (490)	...	219
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Good	...	253
317L	S31703	...	...	1	20 (68)	...	Resistant	...	253
317L	S31703	...	...	1	70 (158)	...	Resistant	...	253
317L	S31703	...	...	1	Boiling	...	Good	...	253
317L	S31703	...	...	2.5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	2.5	70 (158)	...	Resistant	...	253
317L	S31703	...	...	2.5	Boiling	...	Questionable	...	253
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	5	70 (158)	...	Good	...	253
317L	S31703	...	...	5	Boiling	...	Questionable	...	253
317L	S31703	...	...	7.5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	7.5	70 (158)	...	Good	...	253
317L	S31703	...	...	7.5	Boiling	...	Questionable	...	253
317L	S31703	...	...	10	20 (68)	...	Good	...	253
317L	S31703	...	...	10	70 (158)	...	Questionable	...	253
317L	S31703	...	...	10	Boiling	...	Questionable	...	253
317L	S31703	...	...	20	20 (68)	...	Good	...	253
317L	S31703	...	...	20	70 (158)	...	Questionable	...	253
317L	S31703	...	...	20	Boiling	...	Poor	...	253
317L	S31703	...	...	40	20 (68)	...	Good	...	253
317L	S31703	...	...	40	70 (158)	...	Questionable	...	253
317L	S31703	...	...	40	Boiling	...	Poor	...	253
317L	S31703	...	...	60	20 (68)	...	Questionable	...	253
317L	S31703	...	...	60	70 (158)	...	Poor	...	253
317L	S31703	...	...	60	Boiling	...	Poor	...	253
317L	S31703	...	...	80	20 (68)	...	Good	...	253
317L	S31703	...	...	80	70 (158)	...	Questionable	...	253
317L	S31703	...	...	80	Boiling	...	Poor	...	253
317L	S31703	...	...	98	20 (68)	...	Resistant	...	253
317L	S31703	...	...	98	70 (158)	...	Questionable	...	253
317L	S31703	...	...	98	150 (302)	...	Questionable	...	253
317L	S31703	...	...	98	Boiling	...	Poor	...	253
317L	S31703	...	Dissolved completely	50	Boiling	48 h	...	...	97
317L	S31703	...	Dissolved completely	50	Boiling	48 h	...	...	97
317L	S31703	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
317L	S31703	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
317L	S31703	...	Plus 0.5% HCl	50	Boiling	48 h	14 (540)	...	97
317L	S31703	...	Plus 0.5% HCl	50	Boiling	48 h	24 (960)	...	97
317L	S31703	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
317L	S31703	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
317L	S31703	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
317L	S31703	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
317L	S31703	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317L	S31703	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
317L	S31703	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
317L	S31703	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
317L	S31703	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
317L	S31703	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
317L	S31703	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
317L	S31703	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
317L	S31703	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
317L	S31703	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
317L	S31703	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Good	...	253
317LN	S31725	...	...	1	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	1	70 (158)	...	Resistant	...	253
317LN	S31725	...	...	1	Boiling	...	Good	...	253
317LN	S31725	...	...	2.5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	2.5	70 (158)	...	Resistant	...	253
317LN	S31725	...	...	2.5	Boiling	...	Questionable	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	70 (158)	...	Good	...	253
317LN	S31725	...	...	5	Boiling	...	Questionable	...	253
317LN	S31725	...	...	7.5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	7.5	70 (158)	...	Good	...	253
317LN	S31725	...	...	7.5	Boiling	...	Questionable	...	253
317LN	S31725	...	...	10	20 (68)	...	Good	...	253
317LN	S31725	...	...	10	70 (158)	...	Questionable	...	253
317LN	S31725	...	...	10	Boiling	...	Questionable	...	253
317LN	S31725	...	...	20	20 (68)	...	Good	...	253
317LN	S31725	...	...	20	70 (158)	...	Questionable	...	253
317LN	S31725	...	...	20	Boiling	...	Poor	...	253
317LN	S31725	...	...	40	20 (68)	...	Good	...	253
317LN	S31725	...	...	40	70 (158)	...	Questionable	...	253
317LN	S31725	...	...	40	Boiling	...	Poor	...	253
317LN	S31725	...	...	60	20 (68)	...	Questionable	...	253
317LN	S31725	...	...	60	70 (158)	...	Poor	...	253
317LN	S31725	...	...	60	Boiling	...	Poor	...	253
317LN	S31725	...	...	80	20 (68)	...	Good	...	253
317LN	S31725	...	...	80	70 (158)	...	Questionable	...	253
317LN	S31725	...	...	80	Boiling	...	Poor	...	253
317LN	S31725	...	...	98	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	98	70 (158)	...	Questionable	...	253
317LN	S31725	...	...	98	150 (302)	...	Questionable	...	253
317LN	S31725	...	...	98	Boiling	...	Poor	...	253
317LN	S31725	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
317LN	S31725	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
317LN	S31725	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
317LN	S31725	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
317LN	S31725	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
317LN	S31725	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
317LN	S31725	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
317LN	S31725	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
317LN	S31725	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
317LN	S31725	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
317LN	S31725	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
317LN	S31725	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
317LN	S31725	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
317LN	S31725	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
317LN	S31725	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
317LN	S31725	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Questionable	...	253
321	S32100	...	...	1	20 (68)	...	Good	...	253
321	S32100	...	...	1	70 (158)	...	Good	...	253
321	S32100	...	...	1	Boiling	...	Good	...	253
321	S32100	...	...	2.5	20 (68)	...	Good	...	253
321	S32100	...	...	2.5	70 (158)	...	Good	...	253
321	S32100	...	...	2.5	Boiling	...	Questionable	...	253
321	S32100	...	...	5	20 (68)	...	Good	...	253
321	S32100	...	...	5	70 (158)	...	Good	...	253
321	S32100	...	...	5	Boiling	...	Poor	...	253
321	S32100	...	...	7.5	20 (68)	...	Good	...	253
321	S32100	...	...	7.5	70 (158)	...	Good	...	253
321	S32100	...	...	7.5	Boiling	...	Questionable	...	253
321	S32100	...	...	10	20 (68)	...	Questionable	...	253
321	S32100	...	...	10	70 (158)	...	Questionable	...	253
321	S32100	...	...	10	Boiling	...	Poor	...	253
321	S32100	...	...	20	20 (68)	...	Good	...	253
321	S32100	...	...	20	70 (158)	...	Questionable	...	253
321	S32100	...	...	20	Boiling	...	Poor	...	253
321	S32100	...	...	40	20 (68)	...	Good	...	253
321	S32100	...	...	40	70 (158)	...	Questionable	...	253
321	S32100	...	...	40	Boiling	...	Poor	...	253
321	S32100	...	...	60	20 (68)	...	Poor	...	253
321	S32100	...	...	60	70 (158)	...	Poor	...	253
321	S32100	...	...	60	Boiling	...	Poor	...	253
321	S32100	...	...	80	20 (68)	...	Good	...	253
321	S32100	...	...	80	70 (158)	...	Poor	...	253
321	S32100	...	...	80	Boiling	...	Poor	...	253
321	S32100	...	...	98	20 (68)	...	Resistant	...	253
321	S32100	...	...	98	70 (158)	...	Questionable	...	253
321	S32100	...	...	98	150 (302)	...	Questionable	...	253
321	S32100	...	...	98	Boiling	...	Poor	...	253
321	S32100	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
321	S32100	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
321	S32100	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
321	S32100	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
321	S32100	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
321	S32100	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
321	S32100	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
321	S32100	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
321	S32100	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
321	S32100	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
321	S32100	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
321	S32100	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
321	S32100	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
321	S32100	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
321	S32100	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
321	S32100	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
321	S32100	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
321	S32100	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
321	S32100	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Good	...	253
329	S32900	...	...	1	20 (68)	...	Resistant	...	253
329	S32900	...	...	1	70 (158)	...	Resistant	...	253
329	S32900	...	...	1	Boiling	...	Good	...	253
329	S32900	...	...	2.5	20 (68)	...	Resistant	...	253
329	S32900	...	...	2.5	70 (158)	...	Resistant	...	253
329	S32900	...	...	2.5	Boiling	...	Questionable	...	253
329	S32900	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	70 (158)	...	Good	...	253
329	S32900	...	...	5	Boiling	...	Questionable	...	253
329	S32900	...	...	7.5	20 (68)	...	Resistant	...	253
329	S32900	...	...	7.5	70 (158)	...	Good	...	253
329	S32900	...	...	7.5	Boiling	...	Questionable	...	253
329	S32900	...	...	10	20 (68)	...	Good	...	253
329	S32900	...	...	10	70 (158)	...	Questionable	...	253
329	S32900	...	...	10	Boiling	...	Questionable	...	253
329	S32900	...	...	20	20 (68)	...	Good	...	253
329	S32900	...	...	20	70 (158)	...	Questionable	...	253
329	S32900	...	...	20	Boiling	...	Poor	...	253
329	S32900	...	...	40	20 (68)	...	Good	...	253
329	S32900	...	...	40	70 (158)	...	Questionable	...	253
329	S32900	...	...	40	Boiling	...	Poor	...	253
329	S32900	...	...	60	20 (68)	...	Questionable	...	253
329	S32900	...	...	60	70 (158)	...	Poor	...	253
329	S32900	...	...	60	Boiling	...	Poor	...	253
329	S32900	...	...	80	20 (68)	...	Good	...	253
329	S32900	...	...	80	70 (158)	...	Questionable	...	253
329	S32900	...	...	80	Boiling	...	Poor	...	253
329	S32900	...	...	98	20 (68)	...	Resistant	...	253
329	S32900	...	...	98	70 (158)	...	Questionable	...	253
329	S32900	...	...	98	150 (302)	...	Questionable	...	253
329	S32900	...	...	98	Boiling	...	Poor	...	253
329	S32900	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
329	S32900	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
329	S32900	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
329	S32900	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
329	S32900	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
329	S32900	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
329	S32900	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
329	S32900	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
329	S32900	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
329	S32900	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
329	S32900	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
329	S32900	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
329	S32900	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
329	S32900	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
329	S32900	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
329	S32900	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
329	S32900	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
329	S32900	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
329	S32900	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Questionable	...	253
347	S34700	...	...	1	20 (68)	...	Good	...	253
347	S34700	...	...	1	70 (158)	...	Good	...	253
347	S34700	...	...	1	Boiling	...	Good	...	253
347	S34700	...	...	2.5	20 (68)	...	Good	...	253
347	S34700	...	...	2.5	70 (158)	...	Good	...	253
347	S34700	...	...	2.5	Boiling	...	Questionable	...	253
347	S34700	...	...	5	20 (68)	...	Good	...	253
347	S34700	...	...	5	70 (158)	...	Good	...	253
347	S34700	...	...	5	Boiling	...	Poor	...	253
347	S34700	...	...	7.5	20 (68)	...	Good	...	253
347	S34700	...	...	7.5	70 (158)	...	Good	...	253
347	S34700	...	...	7.5	Boiling	...	Questionable	...	253
347	S34700	...	...	10	20 (68)	...	Questionable	...	253
347	S34700	...	...	10	70 (158)	...	Questionable	...	253
347	S34700	...	...	10	Boiling	...	Poor	...	253
347	S34700	...	...	20	20 (68)	...	Good	...	253
347	S34700	...	...	20	70 (158)	...	Questionable	...	253
347	S34700	...	...	20	Boiling	...	Poor	...	253
347	S34700	...	...	40	20 (68)	...	Good	...	253
347	S34700	...	...	40	70 (158)	...	Questionable	...	253
347	S34700	...	...	40	Boiling	...	Poor	...	253
347	S34700	...	...	60	20 (68)	...	Poor	...	253
347	S34700	...	...	60	70 (158)	...	Poor	...	253
347	S34700	...	...	60	Boiling	...	Poor	...	253
347	S34700	...	...	80	20 (68)	...	Good	...	253
347	S34700	...	...	80	70 (158)	...	Poor	...	253
347	S34700	...	...	80	Boiling	...	Poor	...	253
347	S34700	...	...	98	20 (68)	...	Resistant	...	253
347	S34700	...	...	98	70 (158)	...	Questionable	...	253
347	S34700	...	...	98	150 (302)	...	Questionable	...	253
347	S34700	...	...	98	Boiling	...	Poor	...	253
347	S34700	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
347	S34700	...	Fuming (11% free SO_3)	...	100 (212)	...	Good	...	253
347	S34700	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
347	S34700	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
347	S34700	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
347	S34700	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
347	S34700	...	Plus 10% HNO_3	70	90 (194)	...	Good	...	253
347	S34700	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
347	S34700	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
347	S34700	...	Plus 15% HNO_3	20	80 (176)	...	Good	...	253
347	S34700	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
347	S34700	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
347	S34700	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
347	S34700	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
347	S34700	...	Plus 25% HNO_3	30	110 (230)	...	Good	...	253
347	S34700	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
347	S34700	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
347	S34700	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
347	S34700	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
403	S40300	...	...	...	Boiling	...	Questionable	...	253
403	S40300	...	...	...	Boiling	...	Poor	...	253
403	S40300	...	...	1	20 (68)	...	Poor	...	253
403	S40300	...	...	1	70 (158)	...	Poor	...	253
403	S40300	...	...	1	Boiling	...	Poor	...	253
403	S40300	...	...	2.5	20 (68)	...	Poor	...	253
403	S40300	...	...	2.5	70 (158)	...	Poor	...	253
403	S40300	...	...	2.5	Boiling	...	Poor	...	253
403	S40300	...	...	5	20 (68)	...	Poor	...	253
403	S40300	...	...	5	70 (158)	...	Poor	...	253
403	S40300	...	...	5	Boiling	...	Poor	...	253
403	S40300	...	...	7.5	20 (68)	...	Poor	...	253
403	S40300	...	...	7.5	70 (158)	...	Poor	...	253
403	S40300	...	...	7.5	Boiling	...	Poor	...	253
403	S40300	...	...	10	20 (68)	...	Poor	...	253
403	S40300	...	...	10	70 (158)	...	Poor	...	253
403	S40300	...	...	10	Boiling	...	Poor	...	253
403	S40300	...	...	20	20 (68)	...	Poor	...	253
403	S40300	...	...	20	70 (158)	...	Poor	...	253
403	S40300	...	...	20	Boiling	...	Poor	...	253
403	S40300	...	...	40	20 (68)	...	Poor	...	253
403	S40300	...	...	40	70 (158)	...	Poor	...	253
403	S40300	...	...	40	Boiling	...	Poor	...	253
403	S40300	...	...	60	20 (68)	...	Poor	...	253
403	S40300	...	...	60	70 (158)	...	Poor	...	253
403	S40300	...	...	60	Boiling	...	Poor	...	253
403	S40300	...	...	80	20 (68)	...	Poor	...	253
403	S40300	...	...	80	70 (158)	...	Poor	...	253
403	S40300	...	...	80	Boiling	...	Poor	...	253
403	S40300	...	...	98	70 (158)	...	Questionable	...	253
403	S40300	...	...	98	150 (302)	...	Poor	...	253
403	S40300	...	...	98	Boiling	...	Poor	...	253
403	S40300	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
403	S40300	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
403	S40300	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
403	S40300	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
403	S40300	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
403	S40300	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
403	S40300	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
403	S40300	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
403	S40300	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
403	S40300	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
403	S40300	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
403	S40300	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
403	S40300	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
403	S40300	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
403	S40300	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
403	S40300	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
405	S40500	...	...	...	Boiling	...	Questionable	...	253
405	S40500	...	...	...	Boiling	...	Poor	...	253
405	S40500	...	...	1	20 (68)	...	Poor	...	253
405	S40500	...	...	1	70 (158)	...	Poor	...	253
405	S40500	...	...	1	Boiling	...	Poor	...	253
405	S40500	...	...	2.5	20 (68)	...	Poor	...	253
405	S40500	...	...	2.5	70 (158)	...	Poor	...	253
405	S40500	...	...	2.5	Boiling	...	Poor	...	253
405	S40500	...	...	5	20 (68)	...	Poor	...	253
405	S40500	...	...	5	70 (158)	...	Poor	...	253
405	S40500	...	...	5	Boiling	...	Poor	...	253
405	S40500	...	...	7.5	20 (68)	...	Poor	...	253
405	S40500	...	...	7.5	70 (158)	...	Poor	...	253
405	S40500	...	...	7.5	Boiling	...	Poor	...	253
405	S40500	...	...	10	20 (68)	...	Poor	...	253
405	S40500	...	...	10	70 (158)	...	Poor	...	253
405	S40500	...	...	10	Boiling	...	Poor	...	253
405	S40500	...	...	20	20 (68)	...	Poor	...	253
405	S40500	...	...	20	70 (158)	...	Poor	...	253
405	S40500	...	...	20	Boiling	...	Poor	...	253
405	S40500	...	...	40	20 (68)	...	Poor	...	253
405	S40500	...	...	40	70 (158)	...	Poor	...	253
405	S40500	...	...	40	Boiling	...	Poor	...	253
405	S40500	...	...	60	20 (68)	...	Poor	...	253
405	S40500	...	...	60	70 (158)	...	Poor	...	253
405	S40500	...	...	60	Boiling	...	Poor	...	253
405	S40500	...	...	80	20 (68)	...	Poor	...	253
405	S40500	...	...	80	70 (158)	...	Poor	...	253
405	S40500	...	...	80	Boiling	...	Poor	...	253
405	S40500	...	...	98	70 (158)	...	Questionable	...	253
405	S40500	...	...	98	150 (302)	...	Poor	...	253
405	S40500	...	...	98	Boiling	...	Poor	...	253
405	S40500	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
405	S40500	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
405	S40500	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
405	S40500	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
405	S40500	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
405	S40500	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
405	S40500	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
405	S40500	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
405	S40500	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
405	S40500	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
405	S40500	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
405	S40500	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
405	S40500	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
405	S40500	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
405	S40500	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253
405	S40500	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
405	S40500	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
409	S40900	...	...	...	Boiling	...	Questionable	...	253
409	S40900	...	...	...	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	1	20 (68)	...	Poor	...	253
409	S40900	...	...	1	70 (158)	...	Poor	...	253
409	S40900	...	...	1	Boiling	...	Poor	...	253
409	S40900	...	...	2.5	20 (68)	...	Poor	...	253
409	S40900	...	...	2.5	70 (158)	...	Poor	...	253
409	S40900	...	...	2.5	Boiling	...	Poor	...	253
409	S40900	...	...	5	20 (68)	...	Poor	...	253
409	S40900	...	...	5	70 (158)	...	Poor	...	253
409	S40900	...	...	5	Boiling	...	Poor	...	253
409	S40900	...	...	7.5	20 (68)	...	Poor	...	253
409	S40900	...	...	7.5	70 (158)	...	Poor	...	253
409	S40900	...	...	7.5	Boiling	...	Poor	...	253
409	S40900	...	...	10	20 (68)	...	Poor	...	253
409	S40900	...	...	10	70 (158)	...	Poor	...	253
409	S40900	...	...	10	Boiling	...	Poor	...	253
409	S40900	...	...	20	20 (68)	...	Poor	...	253
409	S40900	...	...	20	70 (158)	...	Poor	...	253
409	S40900	...	...	20	Boiling	...	Poor	...	253
409	S40900	...	...	40	20 (68)	...	Poor	...	253
409	S40900	...	...	40	70 (158)	...	Poor	...	253
409	S40900	...	...	40	Boiling	...	Poor	...	253
409	S40900	...	...	60	20 (68)	...	Poor	...	253
409	S40900	...	...	60	70 (158)	...	Poor	...	253
409	S40900	...	...	60	Boiling	...	Poor	...	253
409	S40900	...	...	80	20 (68)	...	Poor	...	253
409	S40900	...	...	80	70 (158)	...	Poor	...	253
409	S40900	...	...	80	Boiling	...	Poor	...	253
409	S40900	...	...	98	70 (158)	...	Questionable	...	253
409	S40900	...	...	98	150 (302)	...	Poor	...	253
409	S40900	...	...	98	Boiling	...	Poor	...	253
409	S40900	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
409	S40900	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
409	S40900	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
409	S40900	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
409	S40900	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
409	S40900	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
409	S40900	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
409	S40900	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
409	S40900	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
409	S40900	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
409	S40900	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
409	S40900	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
409	S40900	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
409	S40900	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
409	S40900	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253
409	S40900	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
409	S40900	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
410	S41000	...	...	Conc.	Room	...	Good	...	121
410	S41000	...	...	Dilute	Room	...	Poor	...	121
410	S41000	...	...	...	Boiling	...	Questionable	...	253
410	S41000	...	...	...	Boiling	...	Poor	...	253
410	S41000	...	...	1	20 (68)	...	Poor	...	253
410	S41000	...	...	1	70 (158)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	1	Boiling	...	Poor	...	253
410	S41000	...	...	2.5	20 (68)	...	Poor	...	253
410	S41000	...	...	2.5	70 (158)	...	Poor	...	253
410	S41000	...	...	2.5	Boiling	...	Poor	...	253
410	S41000	...	...	5	20 (68)	...	Poor	...	253
410	S41000	...	...	5	70 (158)	...	Poor	...	253
410	S41000	...	...	5	Boiling	...	Poor	...	253
410	S41000	...	...	7.5	20 (68)	...	Poor	...	253
410	S41000	...	...	7.5	70 (158)	...	Poor	...	253
410	S41000	...	...	7.5	Boiling	...	Poor	...	253
410	S41000	...	...	10	20 (68)	...	Poor	...	253
410	S41000	...	...	10	70 (158)	...	Poor	...	253
410	S41000	...	...	10	Boiling	...	Poor	...	253
410	S41000	...	...	20	20 (68)	...	Poor	...	253
410	S41000	...	...	20	70 (158)	...	Poor	...	253
410	S41000	...	...	20	Boiling	...	Poor	...	253
410	S41000	...	...	40	20 (68)	...	Poor	...	253
410	S41000	...	...	40	70 (158)	...	Poor	...	253
410	S41000	...	...	40	Boiling	...	Poor	...	253
410	S41000	...	...	60	20 (68)	...	Poor	...	253
410	S41000	...	...	60	70 (158)	...	Poor	...	253
410	S41000	...	...	60	Boiling	...	Poor	...	253
410	S41000	...	...	80	20 (68)	...	Poor	...	253
410	S41000	...	...	80	70 (158)	...	Poor	...	253
410	S41000	...	...	80	Boiling	...	Poor	...	253
410	S41000	...	...	98	70 (158)	...	Questionable	...	253
410	S41000	...	...	98	150 (302)	...	Poor	...	253
410	S41000	...	...	98	Boiling	...	Poor	...	253
410	S41000	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
410	S41000	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
410	S41000	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
410	S41000	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
410	S41000	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
410	S41000	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
410	S41000	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
410	S41000	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
410	S41000	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
410	S41000	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
410	S41000	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
410	S41000	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
410	S41000	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
410	S41000	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
410	S41000	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253
410	S41000	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
410	S41000	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
416	S41600	...	...	...	Boiling	...	Questionable	...	253
416	S41600	...	...	...	Boiling	...	Poor	...	253
416	S41600	...	...	1	20 (68)	...	Poor	...	253
416	S41600	...	...	1	70 (158)	...	Poor	...	253
416	S41600	...	...	1	Boiling	...	Poor	...	253
416	S41600	...	...	2.5	20 (68)	...	Poor	...	253
416	S41600	...	...	2.5	70 (158)	...	Poor	...	253
416	S41600	...	...	2.5	Boiling	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
416	S41600	...	...	5	20 (68)	...	Poor	...	253
416	S41600	...	...	5	70 (158)	...	Poor	...	253
416	S41600	...	...	5	Boiling	...	Poor	...	253
416	S41600	...	...	7.5	20 (68)	...	Poor	...	253
416	S41600	...	...	7.5	70 (158)	...	Poor	...	253
416	S41600	...	...	7.5	Boiling	...	Poor	...	253
416	S41600	...	...	10	20 (68)	...	Poor	...	253
416	S41600	...	...	10	70 (158)	...	Poor	...	253
416	S41600	...	...	10	Boiling	...	Poor	...	253
416	S41600	...	...	20	20 (68)	...	Poor	...	253
416	S41600	...	...	20	70 (158)	...	Poor	...	253
416	S41600	...	...	20	Boiling	...	Poor	...	253
416	S41600	...	...	40	20 (68)	...	Poor	...	253
416	S41600	...	...	40	70 (158)	...	Poor	...	253
416	S41600	...	...	40	Boiling	...	Poor	...	253
416	S41600	...	...	60	20 (68)	...	Poor	...	253
416	S41600	...	...	60	70 (158)	...	Poor	...	253
416	S41600	...	...	60	Boiling	...	Poor	...	253
416	S41600	...	...	80	20 (68)	...	Poor	...	253
416	S41600	...	...	80	70 (158)	...	Poor	...	253
416	S41600	...	...	80	Boiling	...	Poor	...	253
416	S41600	...	...	98	70 (158)	...	Questionable	...	253
416	S41600	...	...	98	150 (302)	...	Poor	...	253
416	S41600	...	...	98	Boiling	...	Poor	...	253
416	S41600	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
416	S41600	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
416	S41600	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
416	S41600	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
416	S41600	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
416	S41600	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
416	S41600	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
416	S41600	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
416	S41600	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
416	S41600	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
416	S41600	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
416	S41600	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
416	S41600	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
416	S41600	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
416	S41600	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253
416	S41600	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
416	S41600	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
420	S42000	...	...	...	Boiling	...	Questionable	...	253
420	S42000	...	...	...	Boiling	...	Poor	...	253
420	S42000	...	...	1	20 (68)	...	Poor	...	253
420	S42000	...	...	1	70 (158)	...	Poor	...	253
420	S42000	...	...	1	Boiling	...	Poor	...	253
420	S42000	...	...	2.5	20 (68)	...	Poor	...	253
420	S42000	...	...	2.5	70 (158)	...	Poor	...	253
420	S42000	...	...	2.5	Boiling	...	Poor	...	253
420	S42000	...	...	5	20 (68)	...	Poor	...	253
420	S42000	...	...	5	70 (158)	...	Poor	...	253
420	S42000	...	...	5	Boiling	...	Poor	...	253
420	S42000	...	...	7.5	20 (68)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
420	S42000	...	...	7.5	70 (158)	...	Poor	...	253
420	S42000	...	...	7.5	Boiling	...	Poor	...	253
420	S42000	...	...	10	20 (68)	...	Poor	...	253
420	S42000	...	...	10	70 (158)	...	Poor	...	253
420	S42000	...	...	10	Boiling	...	Poor	...	253
420	S42000	...	...	20	20 (68)	...	Poor	...	253
420	S42000	...	...	20	70 (158)	...	Poor	...	253
420	S42000	...	...	20	Boiling	...	Poor	...	253
420	S42000	...	...	40	20 (68)	...	Poor	...	253
420	S42000	...	...	40	70 (158)	...	Poor	...	253
420	S42000	...	...	40	Boiling	...	Poor	...	253
420	S42000	...	...	60	20 (68)	...	Poor	...	253
420	S42000	...	...	60	70 (158)	...	Poor	...	253
420	S42000	...	...	60	Boiling	...	Poor	...	253
420	S42000	...	...	80	20 (68)	...	Poor	...	253
420	S42000	...	...	80	70 (158)	...	Poor	...	253
420	S42000	...	...	80	Boiling	...	Poor	...	253
420	S42000	...	...	98	70 (158)	...	Questionable	...	253
420	S42000	...	...	98	150 (302)	...	Poor	...	253
420	S42000	...	...	98	Boiling	...	Poor	...	253
420	S42000	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
420	S42000	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
420	S42000	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
420	S42000	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
420	S42000	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
420	S42000	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
420	S42000	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
420	S42000	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
420	S42000	...	Plus 25% HNO_3	75	50 (122)	...	Poor	...	253
420	S42000	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
420	S42000	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
420	S42000	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
420	S42000	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
420	S42000	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
420	S42000	...	Plus 50% HNO_3	50	50 (122)	...	Poor	...	253
420	S42000	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
420	S42000	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
430	S43000	...	...	...	Boiling	...	Good	...	253
430	S43000	...	...	...	Boiling	...	Questionable	...	253
430	S43000	...	...	1	20 (68)	...	Poor	...	253
430	S43000	...	...	1	70 (158)	...	Poor	...	253
430	S43000	...	...	1	Boiling	...	Poor	...	253
430	S43000	...	...	2.5	20 (68)	...	Poor	...	253
430	S43000	...	...	2.5	70 (158)	...	Poor	...	253
430	S43000	...	...	2.5	Boiling	...	Poor	...	253
430	S43000	...	...	5	20 (68)	...	Poor	...	253
430	S43000	...	...	5	70 (158)	...	Poor	...	253
430	S43000	...	...	5	Boiling	...	Poor	...	253
430	S43000	...	...	7.5	20 (68)	...	Poor	...	253
430	S43000	...	...	7.5	70 (158)	...	Poor	...	253
430	S43000	...	...	7.5	Boiling	...	Poor	...	253
430	S43000	...	...	10	20 (68)	...	Poor	...	253
430	S43000	...	...	10	70 (158)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	...	10	Boiling	...	Poor	...	253
430	S43000	...	...	20	20 (68)	...	Poor	...	253
430	S43000	...	...	20	70 (158)	...	Poor	...	253
430	S43000	...	...	20	Boiling	...	Poor	...	253
430	S43000	...	...	40	20 (68)	...	Poor	...	253
430	S43000	...	...	40	70 (158)	...	Poor	...	253
430	S43000	...	...	40	Boiling	...	Poor	...	253
430	S43000	...	...	60	20 (68)	...	Poor	...	253
430	S43000	...	...	60	70 (158)	...	Poor	...	253
430	S43000	...	...	60	Boiling	...	Poor	...	253
430	S43000	...	...	80	20 (68)	...	Poor	...	253
430	S43000	...	...	80	70 (158)	...	Poor	...	253
430	S43000	...	...	80	Boiling	...	Poor	...	253
430	S43000	...	...	98	20 (68)	...	Resistant	...	253
430	S43000	...	...	98	70 (158)	...	Questionable	...	253
430	S43000	...	...	98	150 (302)	...	Poor	...	253
430	S43000	...	...	98	Boiling	...	Poor	...	253
430	S43000	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
430	S43000	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
430	S43000	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
430	S43000	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
430	S43000	...	Plus 1% HNO_3	2	Boiling	...	Poor	...	253
430	S43000	...	Plus 10% HNO_3	70	50 (122)	...	Poor	...	253
430	S43000	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
430	S43000	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
430	S43000	...	Plus 15% HNO_3	20	50 (122)	...	Poor	...	253
430	S43000	...	Plus 15% HNO_3	20	80 (176)	...	Poor	...	253
430	S43000	...	Plus 25% HNO_3	75	50 (122)	...	Questionable	...	253
430	S43000	...	Plus 25% HNO_3	75	90 (194)	...	Poor	...	253
430	S43000	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
430	S43000	...	Plus 25% HNO_3	30	90 (194)	...	Poor	...	253
430	S43000	...	Plus 25% HNO_3	30	110 (230)	...	Poor	...	253
430	S43000	...	Plus 5% HNO_3	15	134 (273)	...	Poor	...	253
430	S43000	...	Plus 50% HNO_3	50	50 (122)	...	Questionable	...	253
430	S43000	...	Plus 50% HNO_3	50	90 (194)	...	Poor	...	253
430	S43000	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Questionable	...	253
434	S43400	...	...	1	20 (68)	...	Questionable	...	253
434	S43400	...	...	1	70 (158)	...	Questionable	...	253
434	S43400	...	...	1	Boiling	...	Poor	...	253
434	S43400	...	...	2.5	20 (68)	...	Poor	...	253
434	S43400	...	...	2.5	70 (158)	...	Poor	...	253
434	S43400	...	...	2.5	Boiling	...	Poor	...	253
434	S43400	...	...	5	20 (68)	...	Poor	...	253
434	S43400	...	...	5	70 (158)	...	Poor	...	253
434	S43400	...	...	5	Boiling	...	Poor	...	253
434	S43400	...	...	7.5	20 (68)	...	Poor	...	253
434	S43400	...	...	7.5	70 (158)	...	Poor	...	253
434	S43400	...	...	7.5	Boiling	...	Poor	...	253
434	S43400	...	...	10	20 (68)	...	Poor	...	253
434	S43400	...	...	10	70 (158)	...	Poor	...	253
434	S43400	...	...	10	Boiling	...	Poor	...	253
434	S43400	...	...	20	20 (68)	...	Poor	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
434	S43400	...	...	20	70 (158)	...	Poor	...	253
434	S43400	...	...	20	Boiling	...	Poor	...	253
434	S43400	...	...	40	20 (68)	...	Poor	...	253
434	S43400	...	...	40	70 (158)	...	Poor	...	253
434	S43400	...	...	40	Boiling	...	Poor	...	253
434	S43400	...	...	60	20 (68)	...	Poor	...	253
434	S43400	...	...	60	70 (158)	...	Poor	...	253
434	S43400	...	...	60	Boiling	...	Poor	...	253
434	S43400	...	...	80	20 (68)	...	Poor	...	253
434	S43400	...	...	80	70 (158)	...	Poor	...	253
434	S43400	...	...	80	Boiling	...	Poor	...	253
434	S43400	...	...	98	20 (68)	...	Resistant	...	253
434	S43400	...	...	98	70 (158)	...	Questionable	...	253
434	S43400	...	...	98	150 (302)	...	Poor	...	253
434	S43400	...	...	98	Boiling	...	Poor	...	253
434	S43400	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
434	S43400	...	Fuming (11% free SO_3)	...	100 (212)	...	Poor	...	253
434	S43400	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
434	S43400	...	Fuming (60% free SO_3)	...	80 (176)	...	Poor	...	253
434	S43400	...	Plus 1% HNO_3	2	Boiling	...	Questionable	...	253
434	S43400	...	Plus 10% HNO_3	70	50 (122)	...	Good	...	253
434	S43400	...	Plus 10% HNO_3	70	90 (194)	...	Poor	...	253
434	S43400	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
434	S43400	...	Plus 15% HNO_3	20	50 (122)	...	Good	...	253
434	S43400	...	Plus 15% HNO_3	20	80 (176)	...	Questionable	...	253
434	S43400	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
434	S43400	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
434	S43400	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
434	S43400	...	Plus 25% HNO_3	30	90 (194)	...	Good	...	253
434	S43400	...	Plus 25% HNO_3	30	110 (230)	...	Questionable	...	253
434	S43400	...	Plus 5% HNO_3	15	134 (273)	...	Questionable	...	253
434	S43400	...	Plus 50% HNO_3	50	50 (122)	...	Good	...	253
434	S43400	...	Plus 50% HNO_3	50	90 (194)	...	Questionable	...	253
434	S43400	...	Plus 50% HNO_3	50	120 (248)	...	Poor	...	253
A-286	K66286	Solution treated	...	10	Boiling	...	0.75 (30)	...	98
AL 2205	S31803	...	...	10	66 (150)	...	.03 (1.2)	...	219
AL 2205	S31803	...	...	10	Boiling	...	5.2 (206)	...	219
AL 2205	S31803	...	...	99	130 (266)	96 h	5.75 (230)	...	224
AL 29-4-2	S44800	...	Activated	1	Boiling	...	.070 (2.6)	...	223
AL 29-4-2	S44800	...	Activated	5	Boiling	...	0.27 (10.7)	...	223
AL 29-4-2	S44800	...	Activated	10	Boiling	...	0.46 (18.1)	...	223
AL 29-4-2	S44800	...	Not activated	1	Boiling	...	.005 (0.2)	...	223
AL 29-4-2	S44800	...	Not activated	5	Boiling	...	0.03 (1.3)	...	223
AL 29-4-2	S44800	...	Not activated	10	Boiling	...	0.02 (0.8)	...	223
AL-6XN	N08367	...	...	10	Boiling	...	2.1 (84)	...	120
AL-6XN	N08367	Welded	...	10	Boiling	...	2.3 (92)	...	120
AL-6XN	N08367	...	...	95	30 (86)	...	0.01 (0.1)	...	120
AL29-4-2	S44800	...	Dilute. Activated before test	1	Boiling	...	0.07 (2.6)	...	98
AL29-4-2	S44800	...	Dilute. Activated before tests	5	Boiling	...	0.27 (11)	...	98
AL29-4-2	S44800	...	Dilute. Activated before tests	10	Boiling	...	0.5 (18)	...	98
AL29-4-2	S44800	...	Dilute. Activated. Sample activated at start of each test period. Five 48-h test periods	1	Boiling	48 h	0.08 (3)	...	39

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
AL29-4-2	S44800	...	Dilute. Activated. Sample activated at start of each test period. Five 48-h test periods	5	Boiling	48 h	0.28 (11)	...	39
AL29-4-2	S44800	...	Dilute. Nonactivated. Five 48-h test periods	1	Boiling	48 h	0.005 (0.2)	...	39
AL29-4-2	S44800	...	Dilute. Nonactivated. Five 48-h test periods	5	Boiling	48 h	0.025 (1)	...	39
Alloy 20	...	...	...	60	50 (122)	...	0.1 (4)	...	120
Alloy 904L	N08904	...	...	10	Boiling	...	3.50 (140)	...	212
Alloy 904L	N08904	...	Plus 42 g/L $Fe_2(SO_4)_3$	56	Boiling	...	0.33 (13)	...	212
Alloy 904L	N08904	...	Plus 5% HNO_3	60	Boiling	...	1.85 (74)	...	212
AM-363	S36300	...	...	...	Room	...	Poor	...	120
Carpenter 20	...	...	Coal by-product processing; slight to moderate aeration; rapid agitation	15	15-30 (59-86)	212 d	0.03 (1.2)	...	89
Carpenter 20	...	...	Lab test; no aeration	50	32 (90)	...	0.10 (3.8)	...	89
Carpenter 20	...	...	Lab test; no aeration	66	32 (90)	...	0.01 (0.3)	...	89
Carpenter 20	...	...	Lab test; no aeration	77.6	32 (90)	...	0.003 (0.1)	...	89
Carpenter 20	...	...	Metal cleaning; strong aeration; rapid agitation	30	54 (130)	62 d	0.01 (0.2)	...	89
Carpenter 20	...	...	Metal cleaning; strong aeration; rapid agitation	30	54 (130)	62 d	0.03 (1.2)	...	89
Carpenter 20	...	...	Metal pickling	10	48-71 (120-160)	23 d	Resistant	...	89
Carpenter 20	...	...	Metal pickling; no aeration; no agitation; cast	8	54 (130)	47 d	0.2 (6)	...	89
Carpenter 20	...	...	Sugar processing. Approx. 10%	10	20-70 (68-152)	97 d	0.003 (0.1) max	...	89
Carpenter 20	...	...	Sugar processing. Approx. 10%	10	20-70 (68-152)	97 d	0.03 (25)	...	89
E-Brite	S44627	...	Activated	1	Boiling	...	13.7 (541)	...	223
E-Brite	S44627	...	Activated	5	Boiling	...	77 (3020)	...	223
E-Brite	S44627	...	Activated	10	Boiling	...	2600 (100000)	...	223
E-Brite	S44627	...	Dilute. Activated. Sample activated at start of each test period. Five 48-h test periods	1	Boiling	48 h	14 (541)	...	39
E-Brite	S44627	...	Dilute. Activated. Sample activated at start of each test period. One period or less	5	Boiling	48 h	77 (3020)	...	39
E-Brite	S44627	...	Dilute. Nonactivated. Five 48-h test periods	1	Boiling	48 h	0.02 (0.7)	...	39
E-Brite	S44627	...	Dilute. Nonactivated. Five 48-h test periods	5	Boiling	48 h	0.36 (14)	...	39
E-Brite	S44627	...	Not activated	1	Boiling	48 h	.020 (0.7)	...	223
E-Brite	S44627	...	Not activated	5	Boiling	...	0.36 (14)	...	223
E-Brite	S44627	...	Not activated	10	Boiling	...	900 (35000)	...	223
F51	S31803	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Good	...	253
F51	S31803	...	...	1	20 (68)	...	Resistant	...	253
F51	S31803	...	...	1	70 (158)	...	Resistant	...	253
F51	S31803	...	...	1	Boiling	...	Good	...	253
F51	S31803	...	...	2.5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	2.5	70 (158)	...	Resistant	...	253
F51	S31803	...	...	2.5	Boiling	...	Questionable	...	253
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	5	70 (158)	...	Good	...	253
F51	S31803	...	...	5	Boiling	...	Questionable	...	253
F51	S31803	...	...	7.5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	7.5	70 (158)	...	Good	...	253
F51	S31803	...	...	7.5	Boiling	...	Questionable	...	253
F51	S31803	...	...	10	20 (68)	...	Good	...	253
F51	S31803	...	...	10	70 (158)	...	Questionable	...	253

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Corrosion Behavior of Various Metals and Alloys in Sulfuric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
F51	S31803	...	...	10	Boiling	...	Questionable	...	253
F51	S31803	...	...	20	20 (68)	...	Good	...	253
F51	S31803	...	...	20	70 (158)	...	Questionable	...	253
F51	S31803	...	...	20	Boiling	...	Poor	...	253
F51	S31803	...	...	40	20 (68)	...	Good	...	253
F51	S31803	...	...	40	70 (158)	...	Questionable	...	253
F51	S31803	...	...	40	Boiling	...	Poor	...	253
F51	S31803	...	...	60	20 (68)	...	Questionable	...	253
F51	S31803	...	...	60	70 (158)	...	Poor	...	253
F51	S31803	...	...	60	Boiling	...	Poor	...	253
F51	S31803	...	...	80	20 (68)	...	Good	...	253
F51	S31803	...	...	80	70 (158)	...	Questionable	...	253
F51	S31803	...	...	80	Boiling	...	Poor	...	253
F51	S31803	...	...	98	20 (68)	...	Resistant	...	253
F51	S31803	...	...	98	70 (158)	...	Questionable	...	253
F51	S31803	...	...	98	150 (302)	...	Questionable	...	253
F51	S31803	...	...	98	Boiling	...	Poor	...	253
F51	S31803	...	Fuming (11% free SO_3)	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Fuming (11% free SO_3)	...	100 (212)	...	Resistant	...	253
F51	S31803	...	Fuming (60% free SO_3)	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Fuming (60% free SO_3)	...	80 (176)	...	Resistant	...	253
F51	S31803	...	Plus 1% HNO_3	2	Boiling	...	Resistant	...	253
F51	S31803	...	Plus 10% HNO_3	70	50 (122)	...	Resistant	...	253
F51	S31803	...	Plus 10% HNO_3	70	90 (194)	...	Resistant	...	253
F51	S31803	...	Plus 10% HNO_3	70	168 (334)	...	Poor	...	253
F51	S31803	...	Plus 15% HNO_3	20	50 (122)	...	Resistant	...	253
F51	S31803	...	Plus 15% HNO_3	20	80 (176)	...	Resistant	...	253
F51	S31803	...	Plus 25% HNO_3	75	50 (122)	...	Good	...	253
F51	S31803	...	Plus 25% HNO_3	75	90 (194)	...	Good	...	253
F51	S31803	...	Plus 25% HNO_3	75	157 (315)	...	Poor	...	253
F51	S31803	...	Plus 25% HNO_3	30	90 (194)	...	Resistant	...	253
F51	S31803	...	Plus 25% HNO_3	30	110 (230)	...	Resistant	...	253
F51	S31803	...	Plus 5% HNO_3	15	134 (273)	...	Good	...	253
F51	S31803	...	Plus 50% HNO_3	50	50 (122)	...	Resistant	...	253
F51	S31803	...	Plus 50% HNO_3	50	90 (194)	...	Good	...	253
F51	S31803	...	Plus 50% HNO_3	50	120 (248)	...	Questionable	...	253
Fe-47Cr (ferrite)	...	...	Reducing	10	Boiling	...	325 (13000)	...	58
Fe-47Cr (ferrite)	...	...	Reducing	50	Boiling	...	575 (23000)	...	58
Fe-47Cr (sigma)	...	...	Reducing	10	Boiling	...	825 (33000)	...	58
Fe-47Cr (sigma)	...	...	Reducing	50	Boiling	...	132 (24000)	...	58
Ferralium	S32550	...	...	5	66 (150)	...	Resistant	...	63
Ferralium	S32550	...	...	5	Boiling	...	0.3 (12)	...	63
Ferralium	S32550	...	...	10	66 (150)	...	Resistant	...	63
Ferralium	S32550	...	...	10	Boiling	...	1.0 (40)	...	63
Ferralium	S32550	...	...	20	66 (150)	...	Resistant	...	63
Ferralium	S32550	...	1*N*	...	Boiling	...	1.2 (46)	...	51
Ferralium 255	S32550	...	...	10	66 (150)	...	.005 (0.2)	...	219
Ferralium 255	S32550	...	...	10	Boiling	...	1.0 (40)	...	219
Ferralium 255	S32550	...	...	99	130 (266)	96 h	0.19 (7.5)	...	224
JS700	N08700	...	...	30	Boiling	48 h	3.9 (150)	...	97
JS700	N08700	...	...	50	Boiling	48 h	6 (247)	...	97
JS700	N08700	...	...	70	Boiling	48 h	1460 (57600)	...	97
JS700	N08700	...	Plus 0.5% HCl	50	Boiling	48 h	22 (880)	...	97

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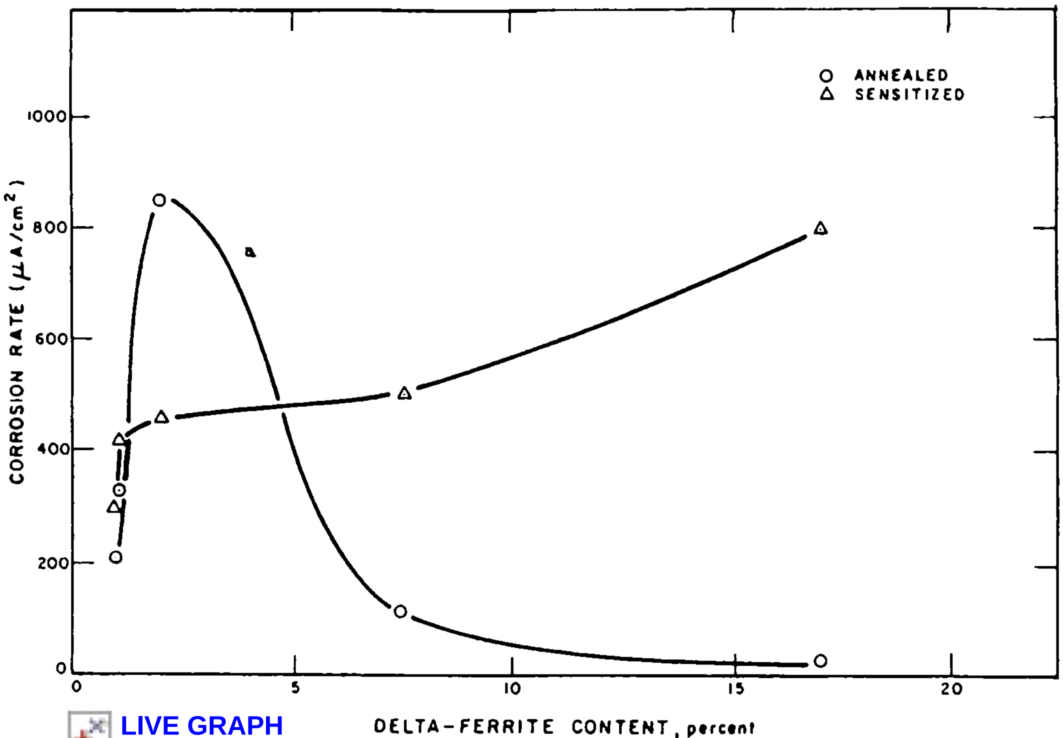

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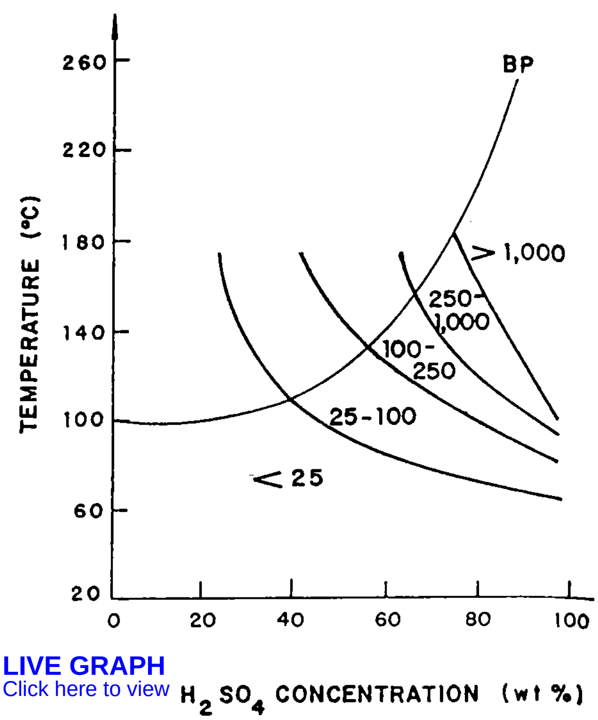
Stainless steel. Variations in the general corrosion rate with delta-ferrite content of 18Cr-Ni type stainless steels in 1 N H_2SO_4 at 25 °C (77 °F). Ref. 263



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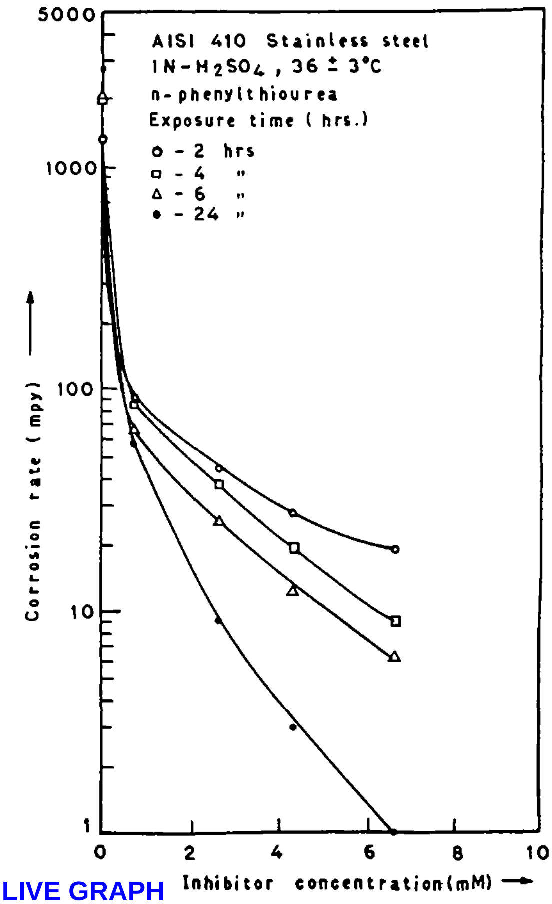
Niobium. Iso-corrosion curves (μm/y) of Nb-25%Ta in sulfuric acid solutions. Ref. 229



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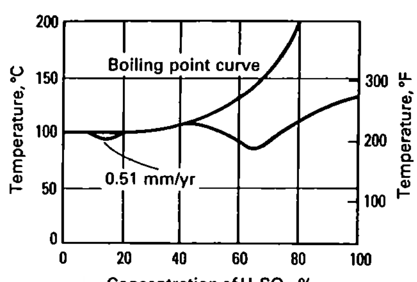
Stainless steel. Variations in the corrosion rate of AISI 410 stainless steel in 1 N H_2SO_4 with *n*-phenylthiourea concentration for different exposure times. Ref. 277



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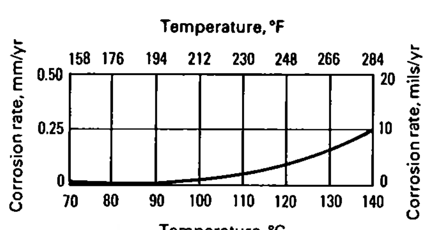
Nickel-base alloy. Isocorrosion diagram for Illium B in sulfuric acid. Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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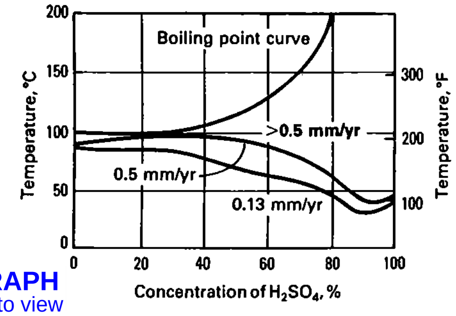
Nickel-base alloy. Corrosion of alloy 55 in 98% sulfuric acid. Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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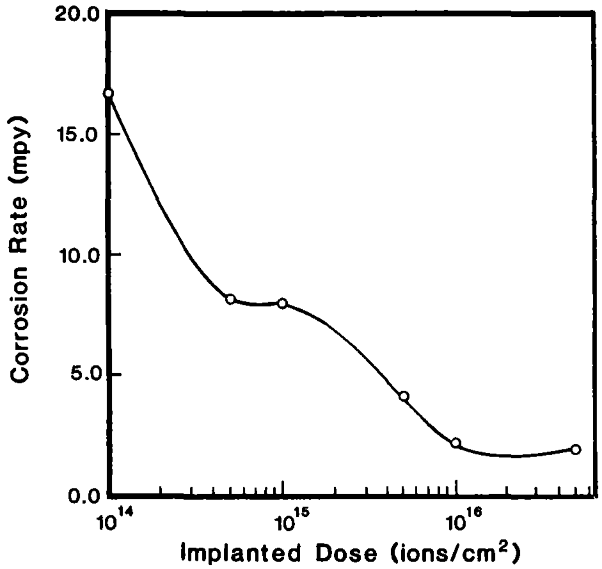
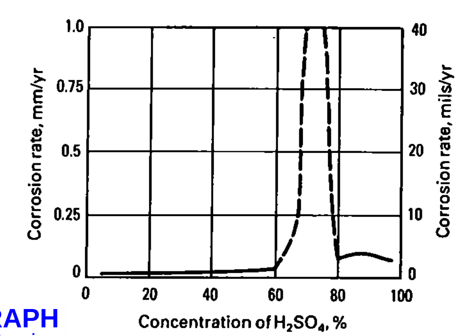
Nickel-base alloy. Isocorrosion diagram for Inconel 625 in sulfuric acid. Source: J.R. Crum and M.E. Adkins, "Correlation of Alloy 625 Electrochemical Behavior with the Sulfuric Acid Isocorrosion Chart," in *Proceedings of the NACE Corrosion/85 Symposium on Corrosion in Sulfuric Acid*, National Association of Corrosion Engineers, Houston, 1985, 23.



Nickel-base alloy. Corrosion rate of Inconel 600 tested in 1.0*N* sulfuric acid vs. the implanted dose of 100 keV BF_2+ions. Source: J.D. Rubio, R.R. Hart, *et al.*, "Effects of BF_2+ Ion Implantation on the Corrosion Resistance of Inconel 600," *Corrosion*, Vol 42, Sept 1986, 557-558.



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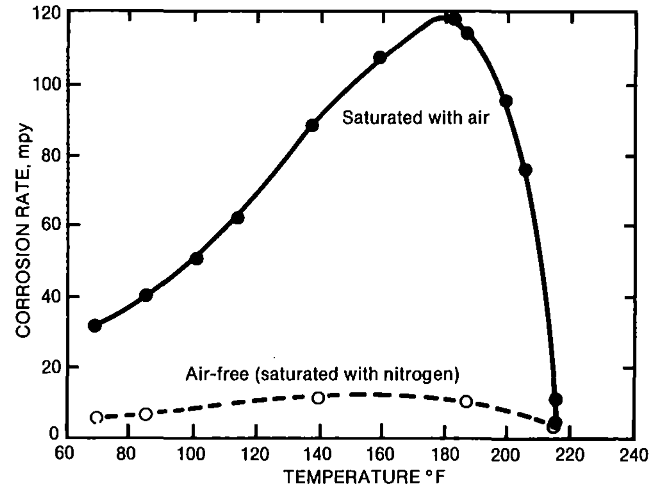
Nickel-base alloy. Corrosion rates of alloy 66 in sulfuric acid solutions at 100 °C (212 °F). Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



Nickel-base alloy. Effect of temperature on corrosion of Monel 400 in sulfuric acid. Concentration, 5 to 6%; velocity, 15.5 to 16.5 ft/min. Source: Inco Alloys International, 1985.

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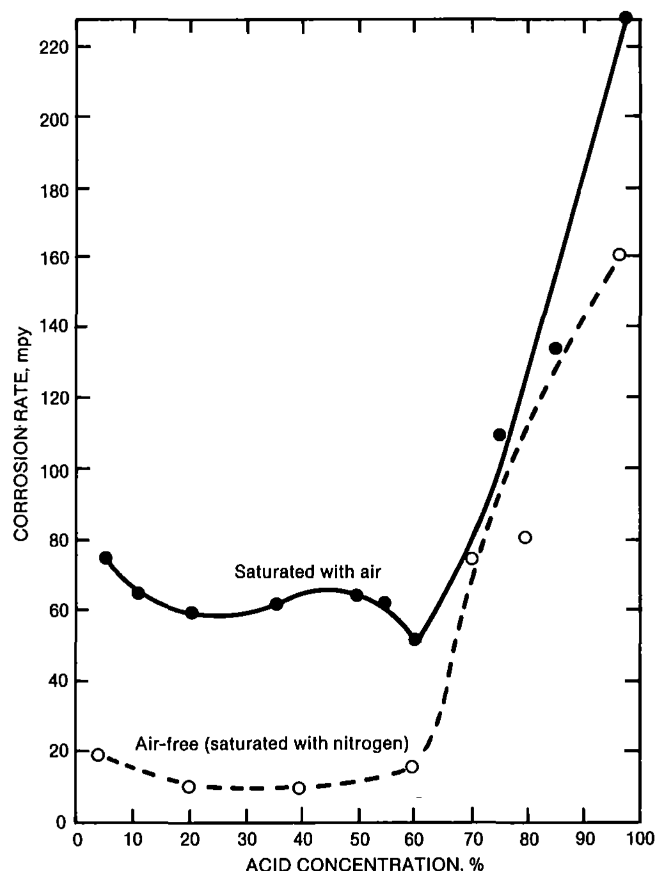

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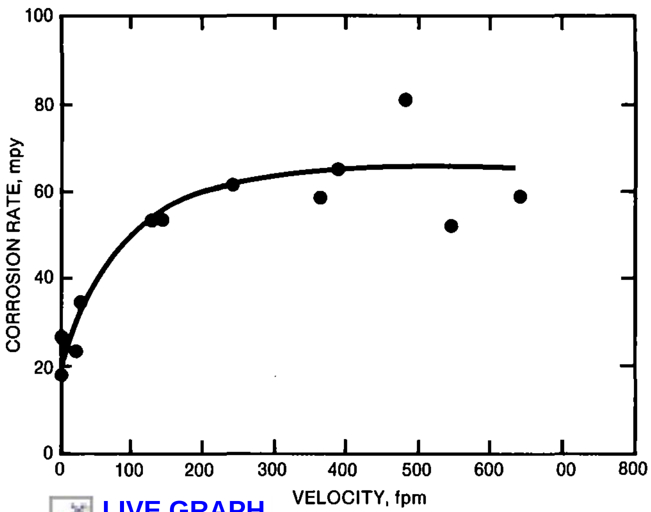
Nickel-base alloy. Corrosion of Monel 400 in sulfuric acid at 95 °C (203 °F); velocity, 16.5 ft/min. Source: Inco Alloys International, 1985.



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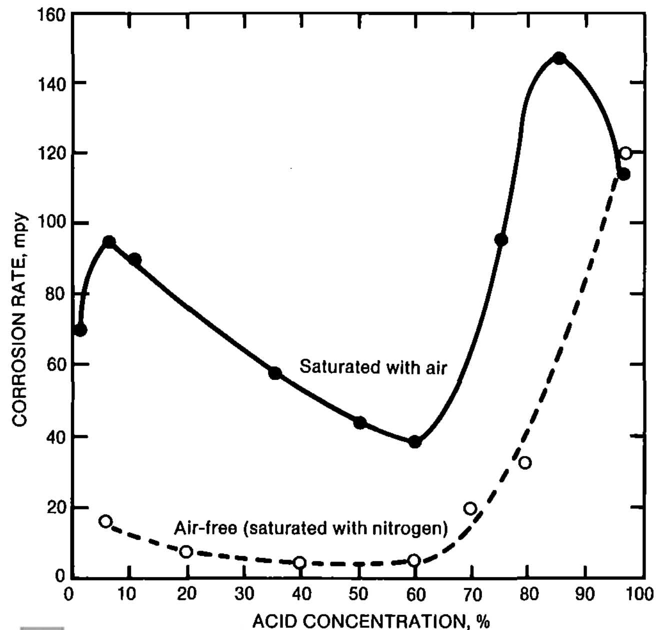
Nickel-base alloy. Effect of velocity on corrosion of Monel 400 in sulfuric acid. 5% concentration, air-saturated solution at room temperature. Source: Inco Alloys International, 1985.



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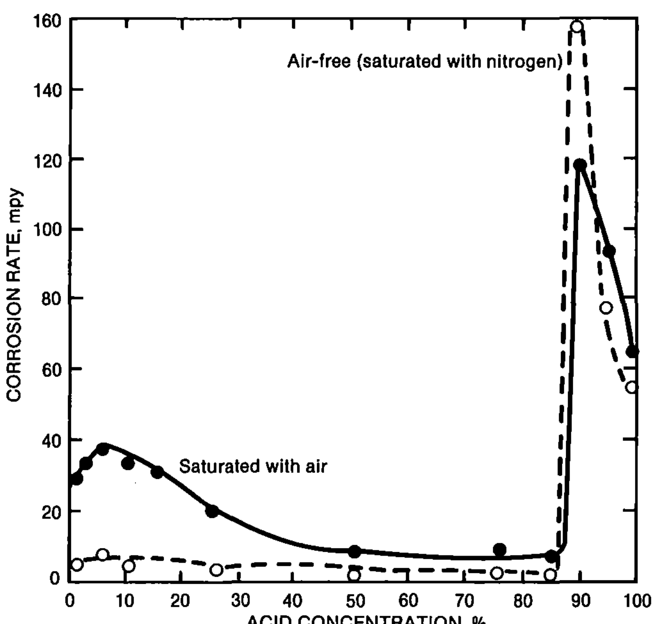
Nickel-base alloy. Corrosion of Monel 400 in sulfuric acid at 60 °C (140 °F); velocity, 16.5 ft/min. Source: Inco Alloys International, 1985.



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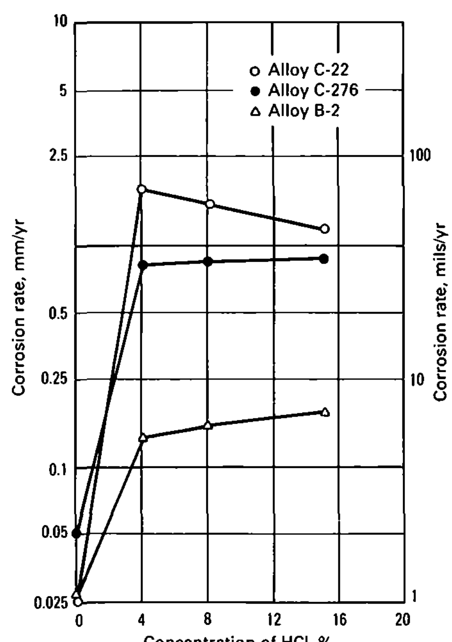
Nickel-base alloy. Corrosion of Monel 400 in sulfuric acid at 30 °C (86 °F); velocity, 17 ft/min. Source: Inco Alloys International, 1985.



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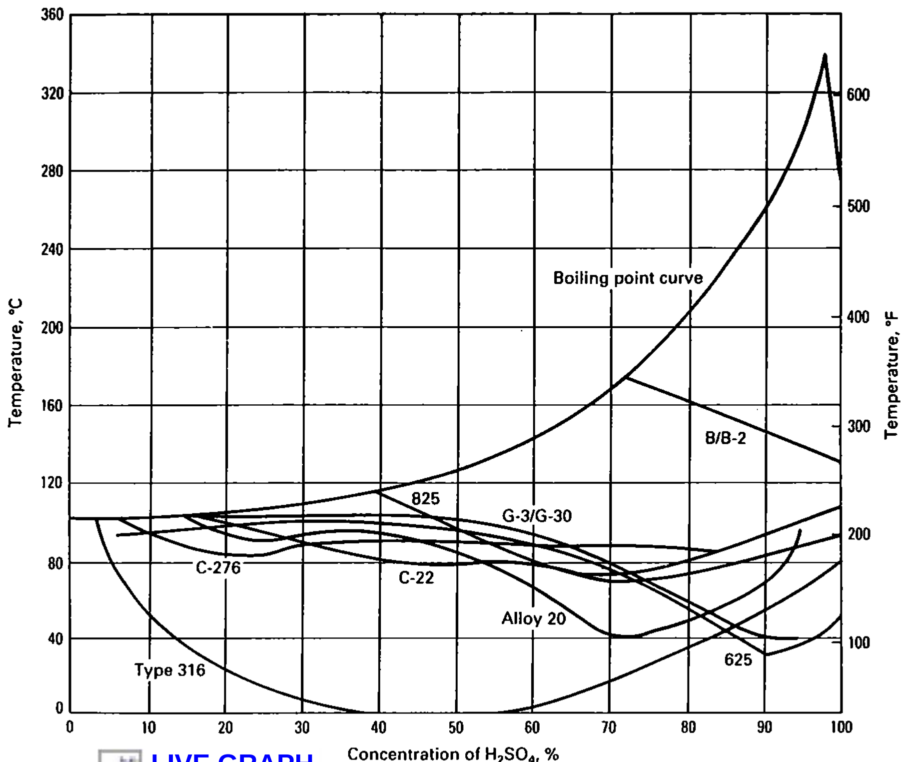
Nickel-base alloys. Effect of hydrochloric acid on the corrosion of various alloys in 15% sulfuric acid at 80 °C (175 °F). Source: N. Sridhar, Paper 182, presented at Corrosion/86, National Association of Corrosion Engineers, Houston, 1986.



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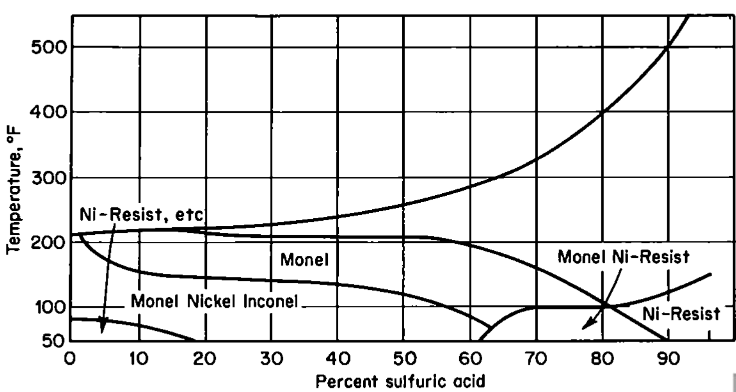
Nickel-base alloys. Comparative behavior of several nickel-base alloys in pure sulfuric acid. The isocorrosion lines indicate a corrosion rate of 0.5 mm/yr (20 mils/yr). Source: J.R. Crum and M.E. Atkins, *Materials Performance*, Vol 25 (No. 2), 1986, 27-32.



Nickel-base alloys. Corrosion of several nickel alloys by sulfuric acid as a function of concentration and temperature. Source: M.G. Fontana and N.D. Greene, *Corrosion Engineering*, McGraw-Hill, New York, 1967, 233.

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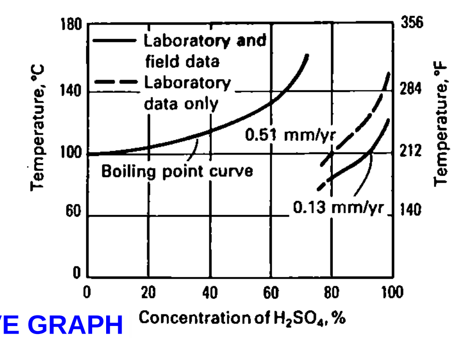

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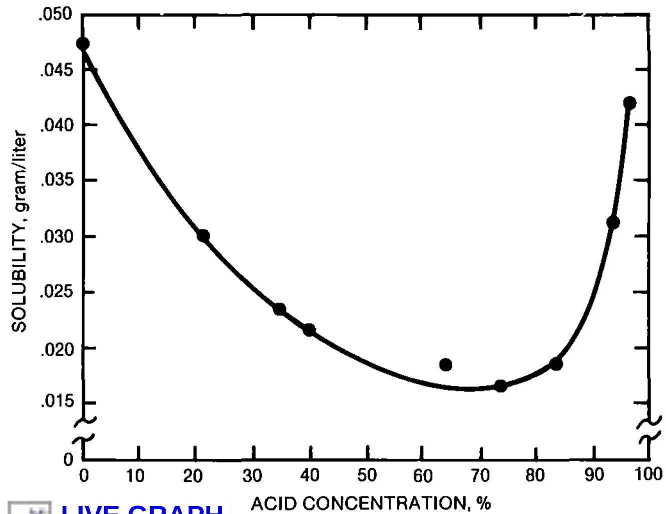
Nickel-base alloy. Isocorrosion diagram for alloy 55 in sulfuric acid. Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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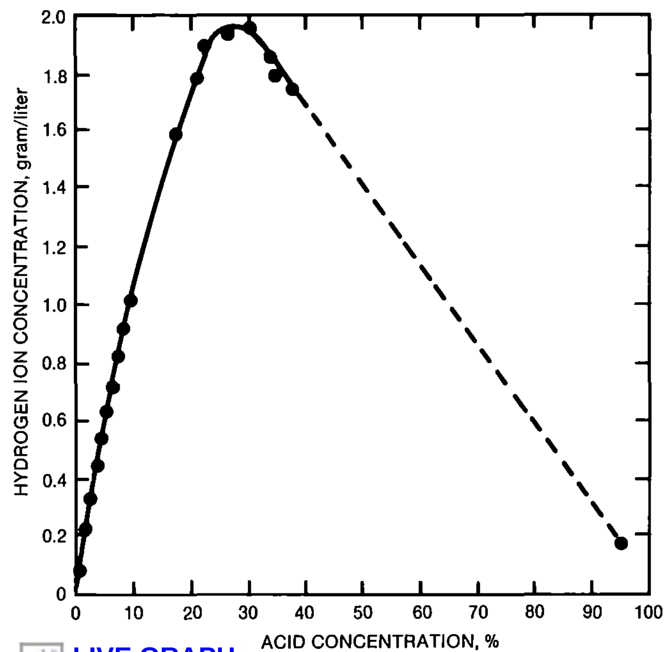
Monel 400. Solubility of oxygen in sulfuric acid at 15 °C (60 °F) at atmospheric pressure. Source: Inco Alloys International, 1985.



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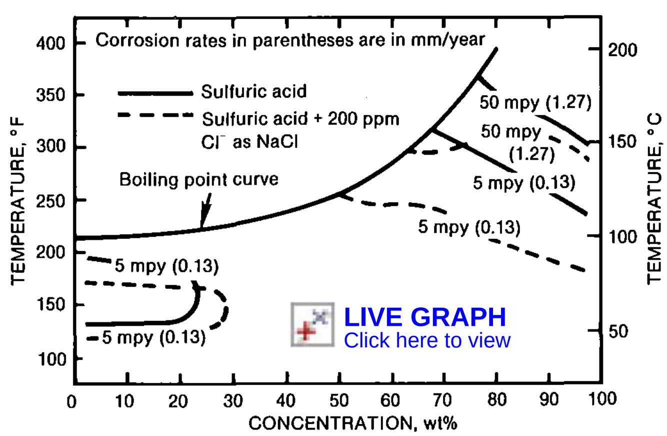
Monel 400. Hydrogen-ion concentration of sulfuric acid at 25 °C (77 °F). Source: Inco Alloys International, 1985.



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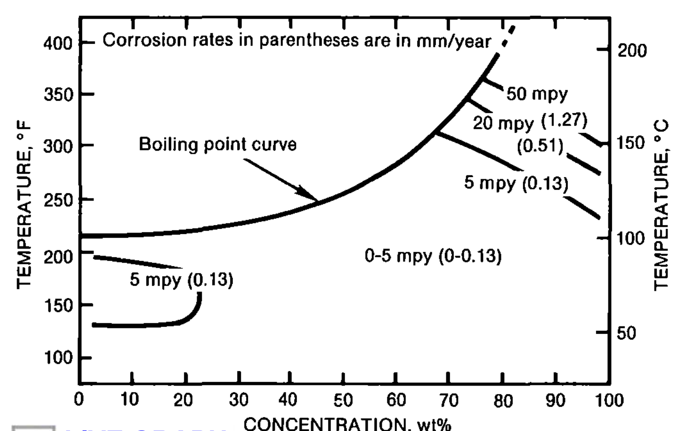
Hastelloy B-2. Corrosion resistance of Hastelloy B-2 to sulfuric acid with 200 ppm chloride ions. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.



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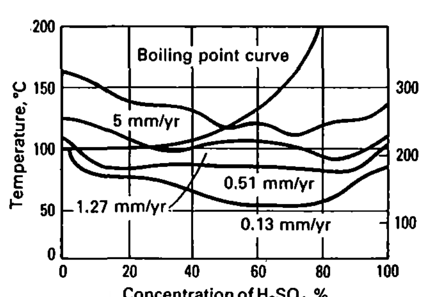
Hastelloy B-2. Corrosion resistance of Hastelloy B-2 to sulfuric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.



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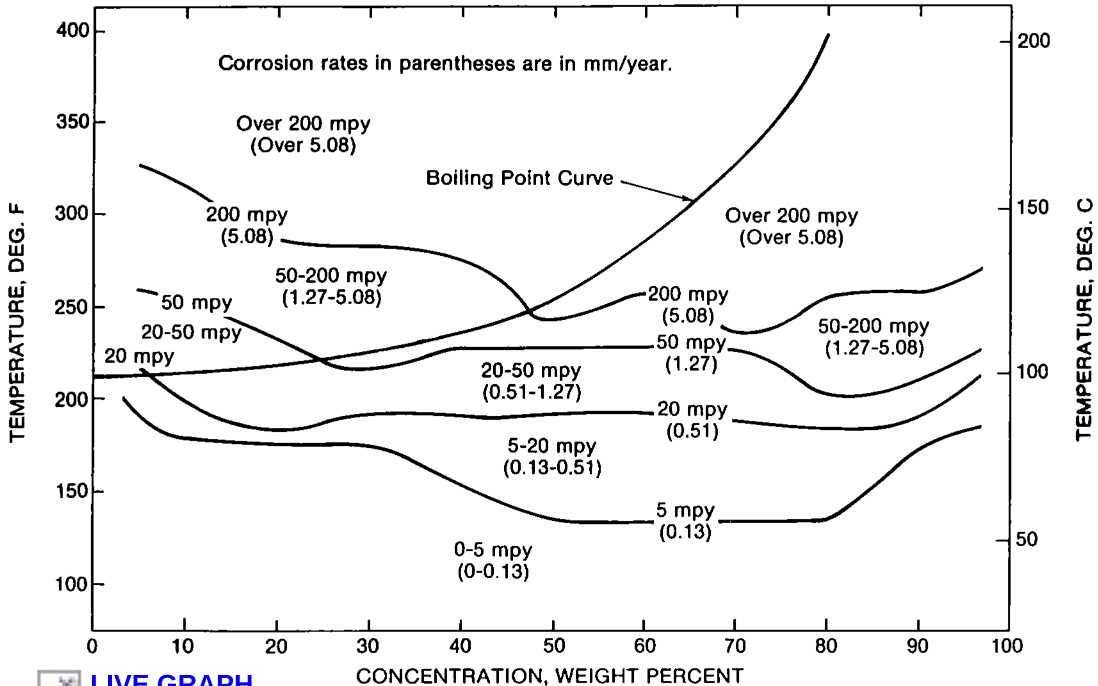
Hastelloy C-276. Isocorrosion diagram for Hastelloy C-276 in sulfuric acid. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1152.



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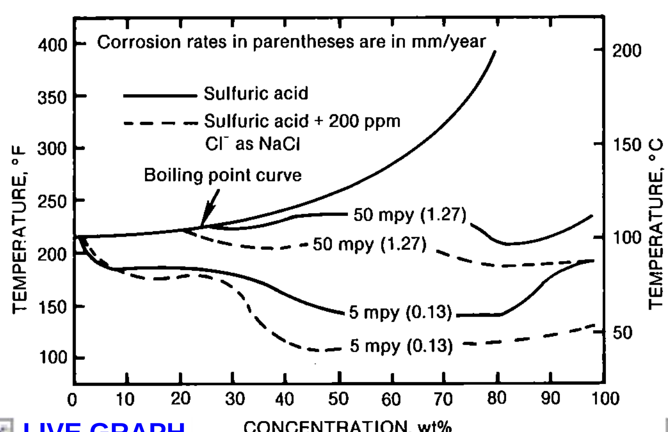
Hastelloy C-276. Resistance to sulfuric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.



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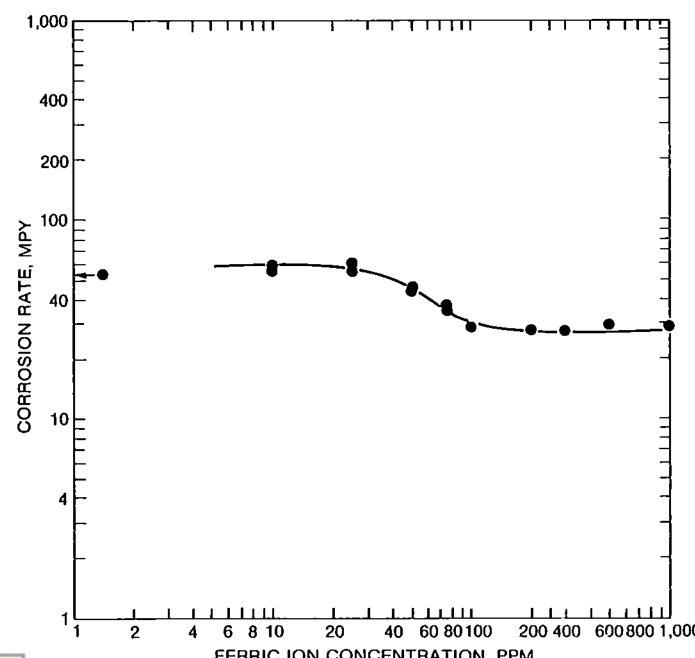
Hastelloy C-276. Resistance to sulfuric acid with 200 ppm chloride ions. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.



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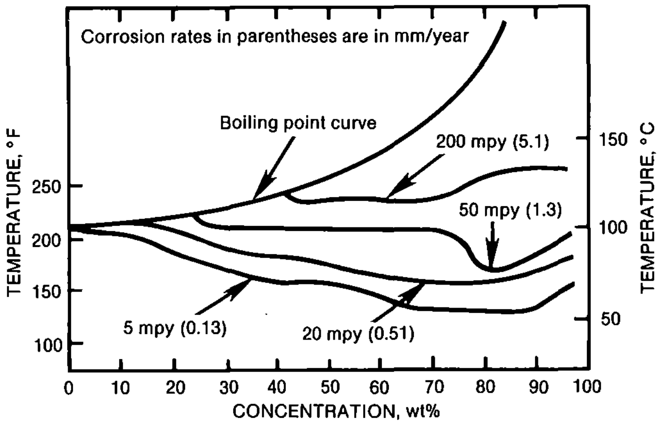
Hastelloy C-276. Effect of ferric ion concentration on corrosion rate in boiling 30% sulfuric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.



Hastelloy C-22. Corrosion resistance of Hastelloy C-22 to sulfuric acid. All test specimens were heat treated at 1121 °C (2050 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.

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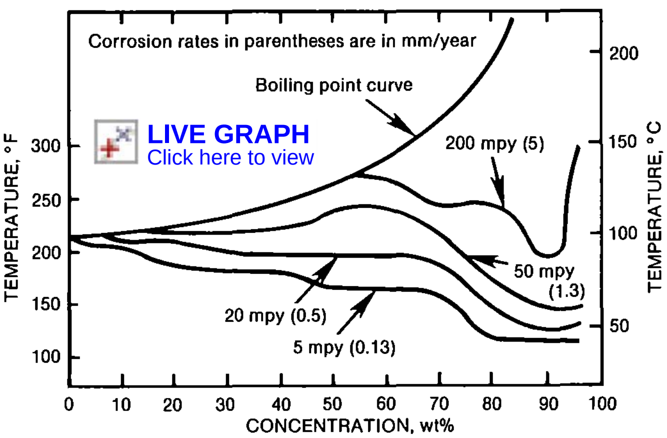

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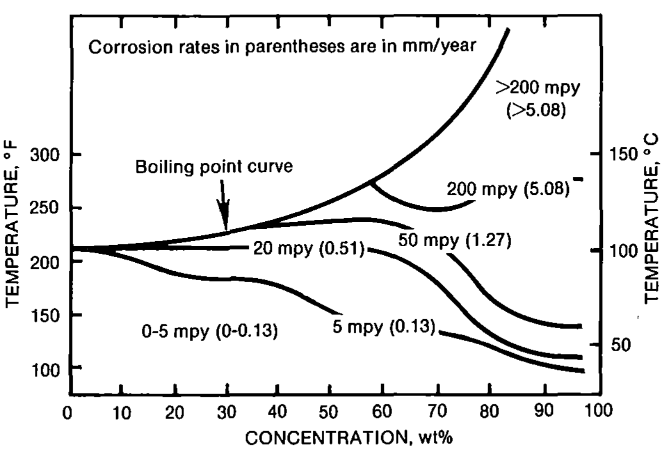
Hastelloy G-30. Corrosion resistance of Hastelloy G-30 to sulfuric acid. All test specimens were heat treated at 1177 °C (2150 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1987.



Hastelloy G-3. Corrosion resistance of Hastelloy G-3 to sulfuric acid. All test specimens were solution heat treated and in the unwelded condition. Source: Haynes International, 1984.

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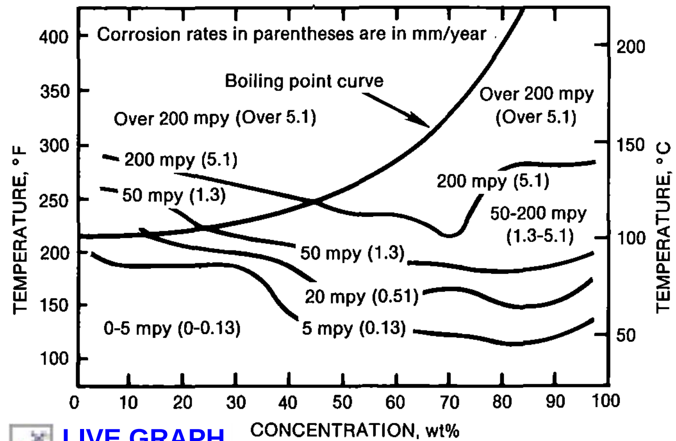

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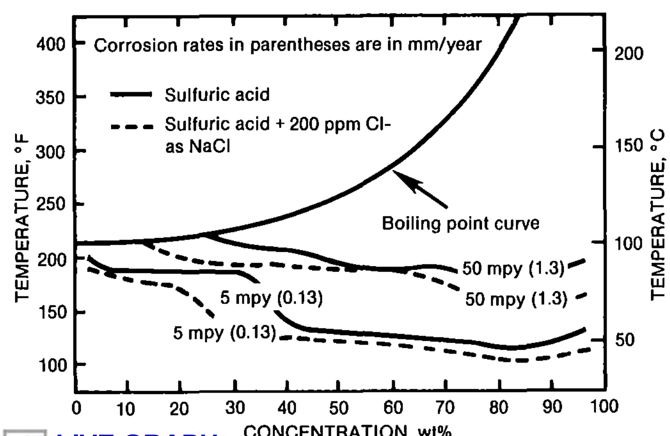
Hastelloy C-4. Corrosion resistance of Hastelloy C-4 to sulfuric acid. All test specimens solution heat treated at 1066 °C (1950 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1984.



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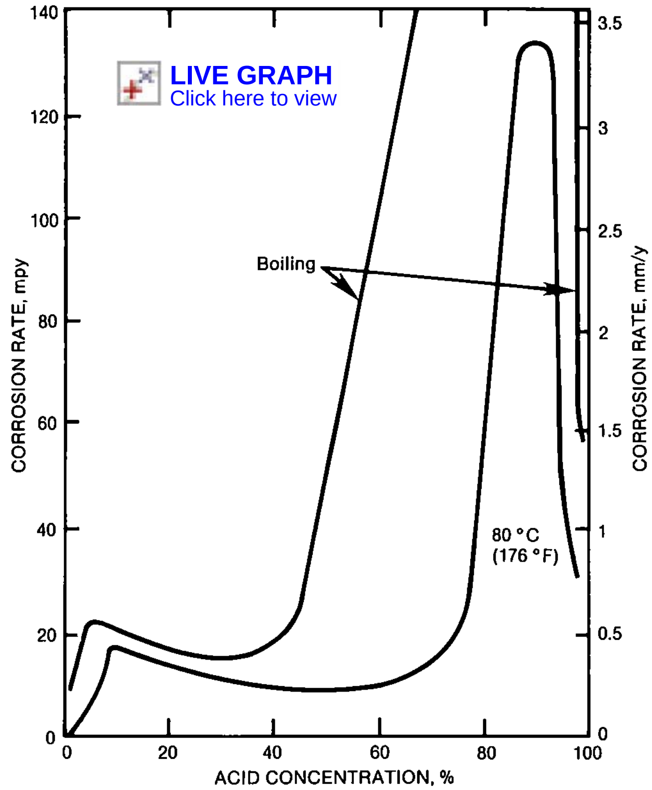
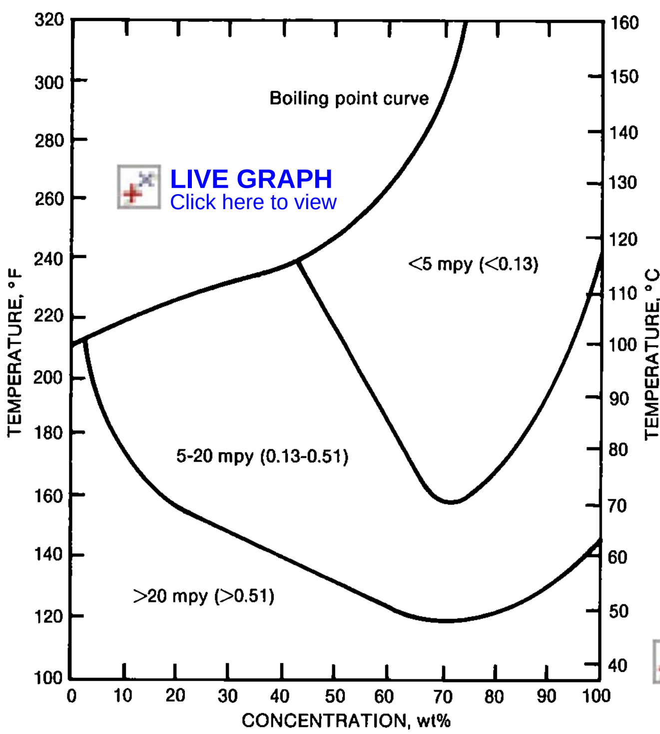
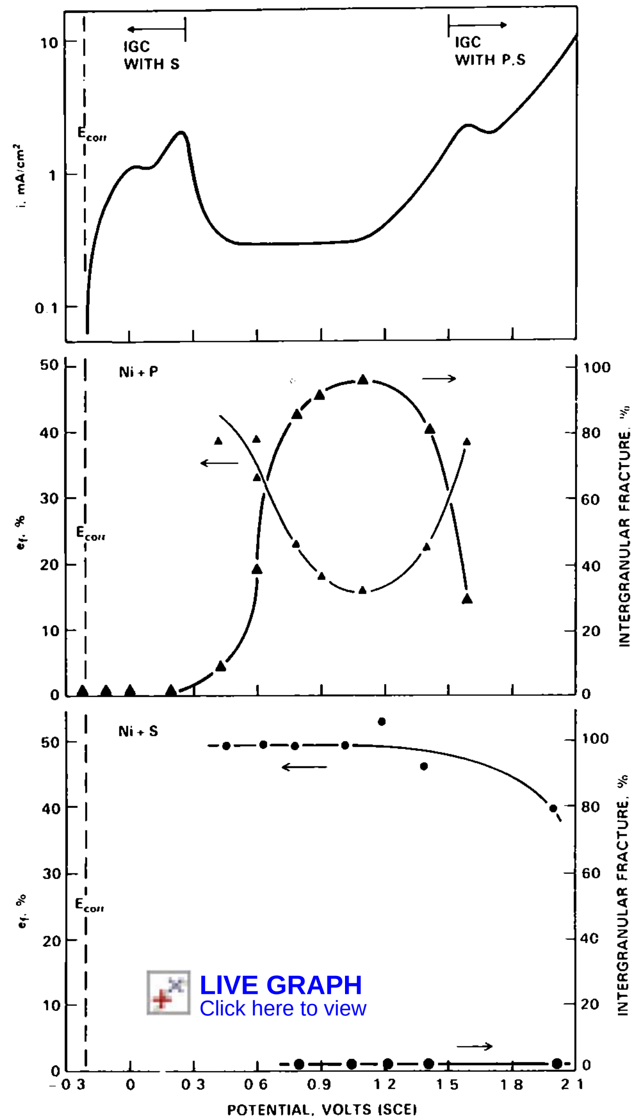
Hastelloy C-4. Corrosion resistance of Hastelloy C-4 to sulfuric acid with 200 ppm chloride ions. All test specimens were solution heat treated at 1066 °C (1950 °F), rapid quenched, and in the unwelded condition. Source: Haynes International, 1984.



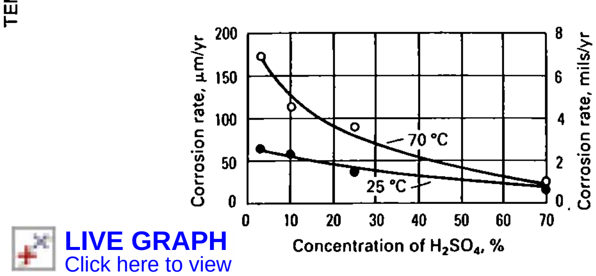
Incoloy 825. Corrosion rates of Incoloy 825 from laboratory tests in chemically pure sulfuric acid. Source: Inco Alloys International, 1987.



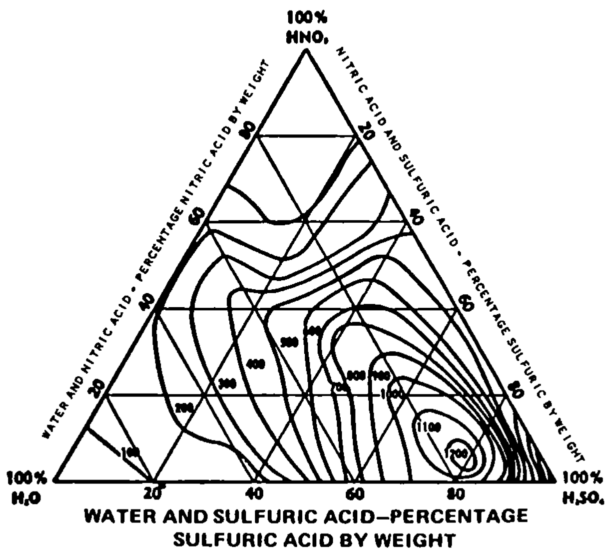
Incoloy 825. Isocorrosion chart for Incoloy 825 in sulfuric acid (based on laboratory tests in pure acid). Source: Inco Alloys International, 1987.



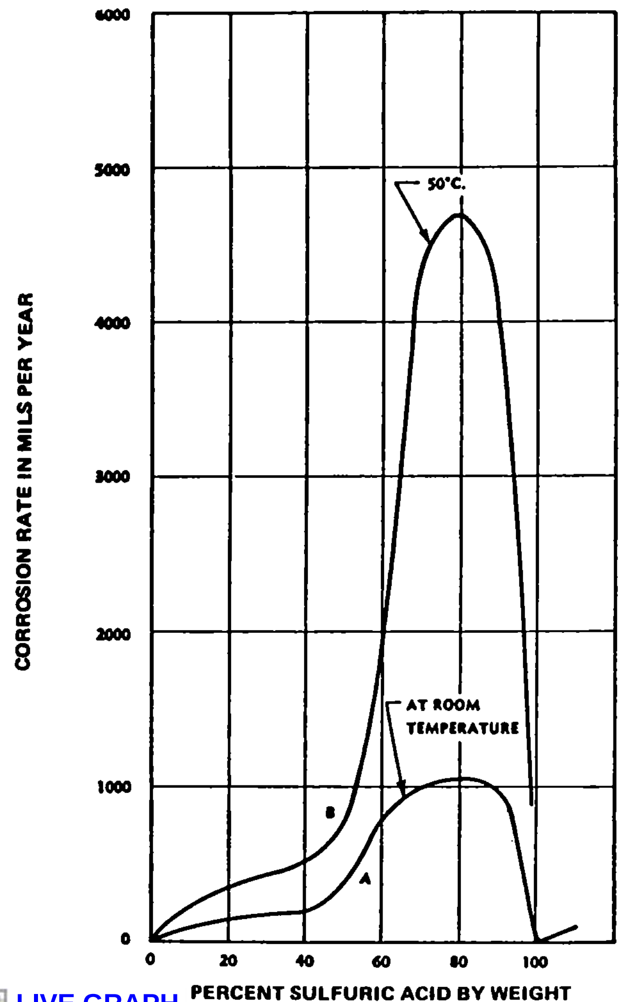
Nickel. Current density, ductility, and percent intergranular fracture for Ni and Ni + P vs. electrochemical potential (SCE). Slow strain rate testing in 1*N* sulfuric acid at 25 °C. Source: R.H. Jones, M.J. Danielson, *et al.*, "Role of Segregated P and S in Intergranular Stress Corrosion Cracking of Ni," *Journal of Materials for Energy Systems*, Vol 8, Sept 1986, 188.



Aluminum. Corrosion of C65500 in sulfuric acid solutions. Specimens were immersed for 48 h at the indicated temperatures. The solution was not agitated or intentionally aerated. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 473.



Aluminum. Resistance of alloy 1100 in various ratios of mixed nitric acid, sulfuric acid, and water. The contours show the average penetration in mils/yr. Source: *Guidelines for the Use of Aluminum with Food and Chemicals*, 5th ed., The Aluminum Association, Washington, DC, 1984, 844.



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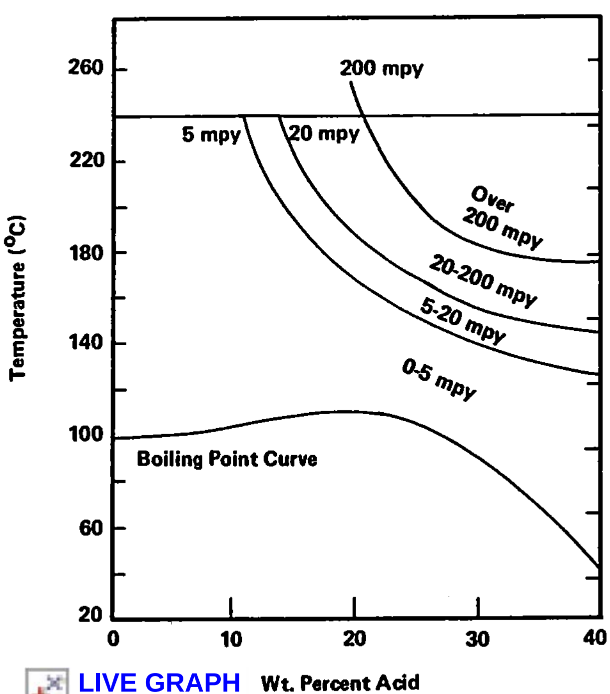
Aluminum. Effect of concentration and temperature on the resistance of alloy 1100 in sulfuric acid. Source: *Guidelines for the Use of Aluminum with Food and Chemicals*, 5th ed., The Aluminum Association, Washington, DC, 1984, 58.



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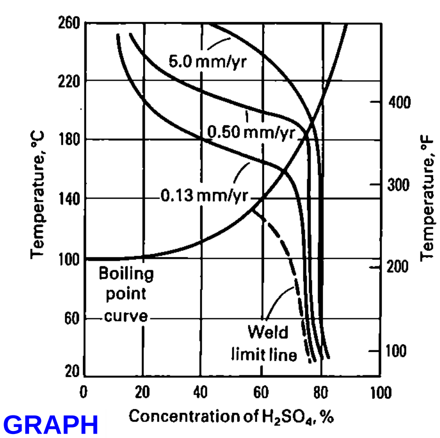
Zirconium. Isocorrosion curves for Grade 702 zirconium in sulfuric acid. Source: B.J. Moniz, "Corrosion Resistance of Zirconium in Chemical Processing Equipment," in *Industrial Applications of Titanium and Zirconium* (STP 830), R.T. Webster, C.S. Young, Ed., ASTM, Philadelphia, 1983, 194.



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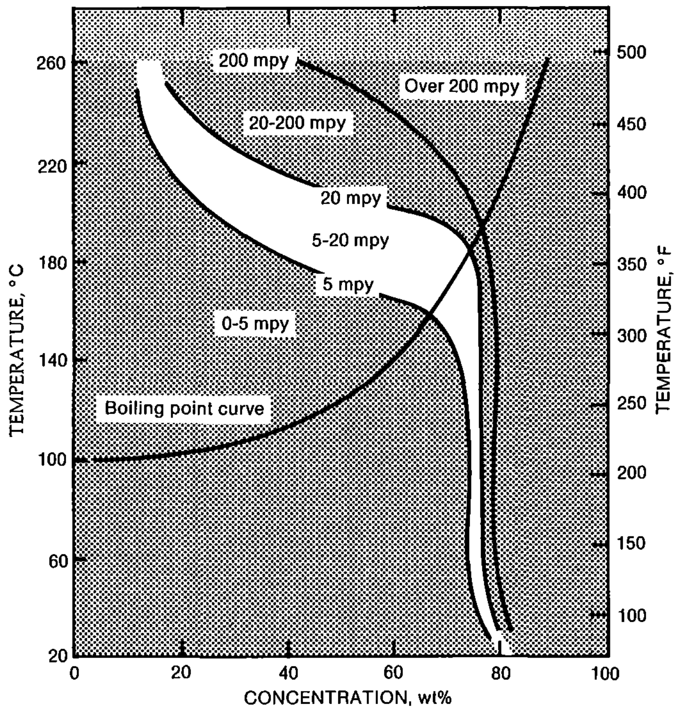
Zirconium. Corrosion of zirconium by sulfuric acid as a function of temperature and acid concentration. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1154.



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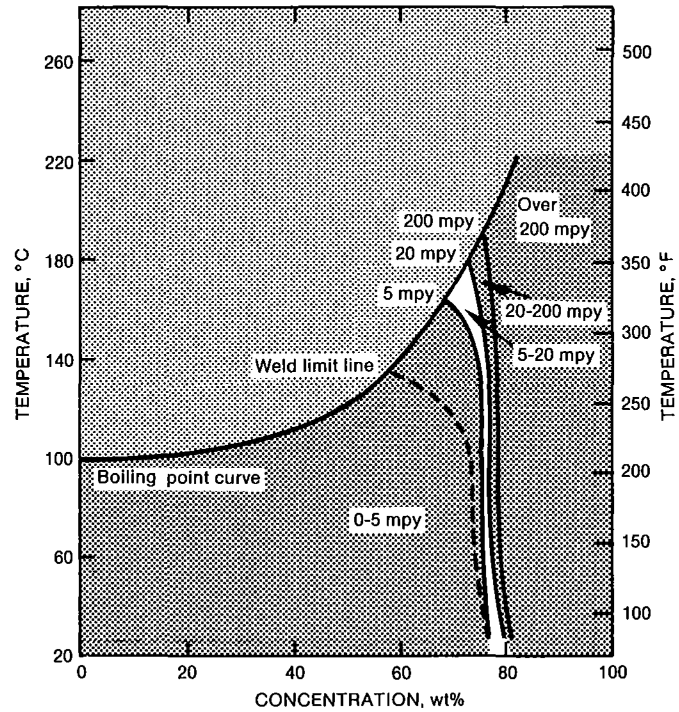

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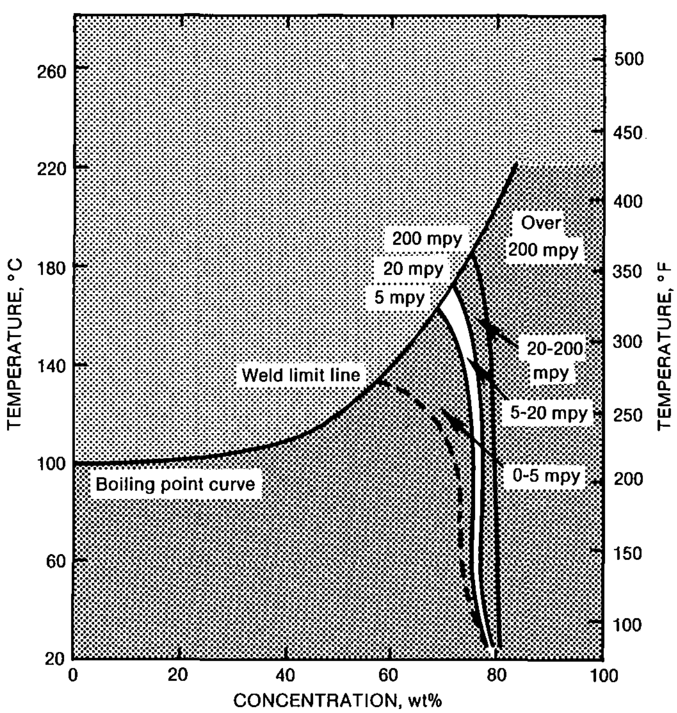

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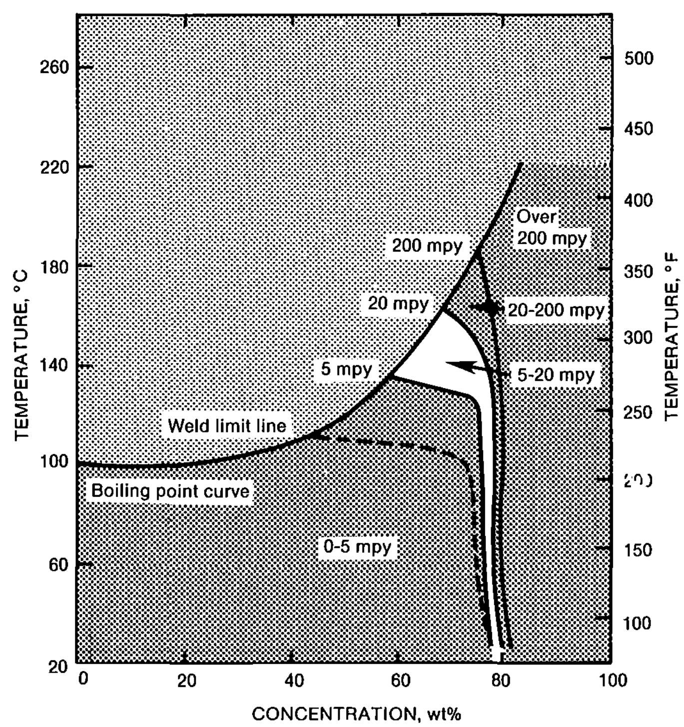

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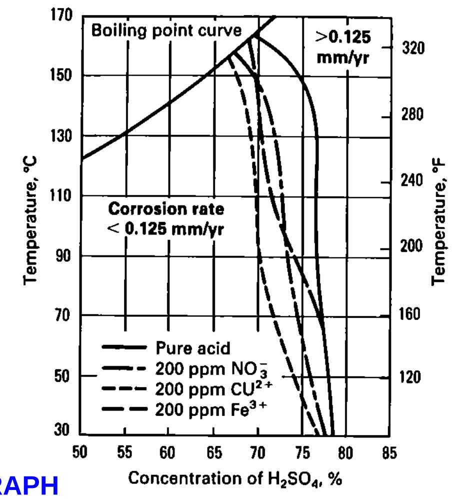
Zirconium. Corrosion of Zircadyne alloys in sulfuric acid solutions. (a) and (b) Zircadyne 702; (c) Zircadyne 704; (d) Zircadyne 705. Source: "Zircadyne Corrosion Properties," Source: Teledyne Wah Chang Albany, 1986.



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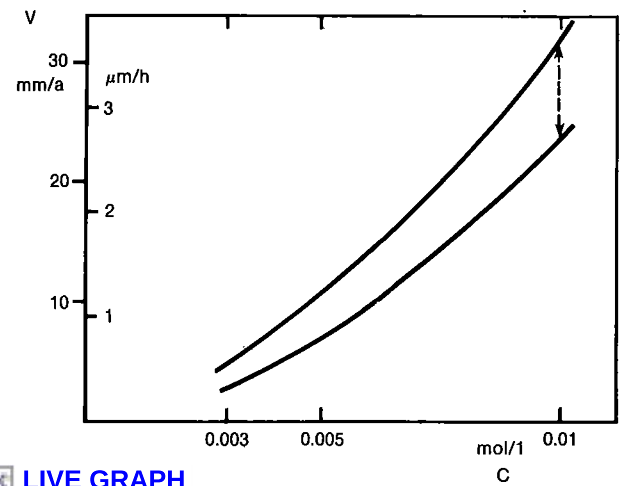
Zirconium. Effect of 200 ppm of various impurities on the 0.125 mm/yr isocorrosion line for zirconium in sulfuric acid. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 709.



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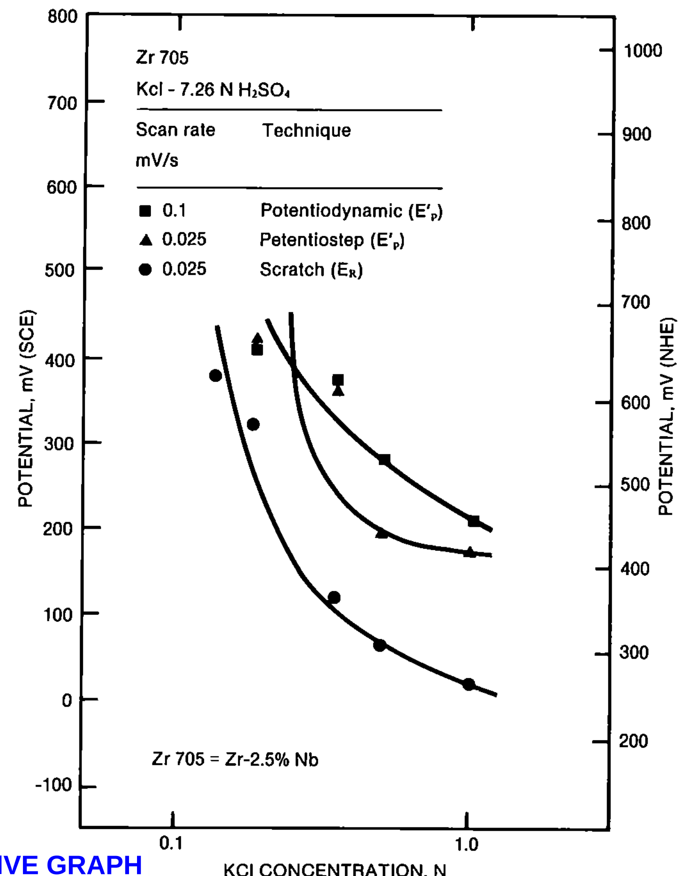
Zirconium. Corrosion rates of Zircaloy-4 as a function of sodium fluoride concentration in sulfuric acid (anodic polarization 1000 mV). Source: J. Vehlow, "Corrosion of Zircaloy-4 in H_2SO_4-NaF and Its Application for Measuring the Distribution Pattern of Fission Products in Zircaloy-4 Fuel Hulls," *Werkstoffe und Korrosion*, Vol 36, May 1985, 197.



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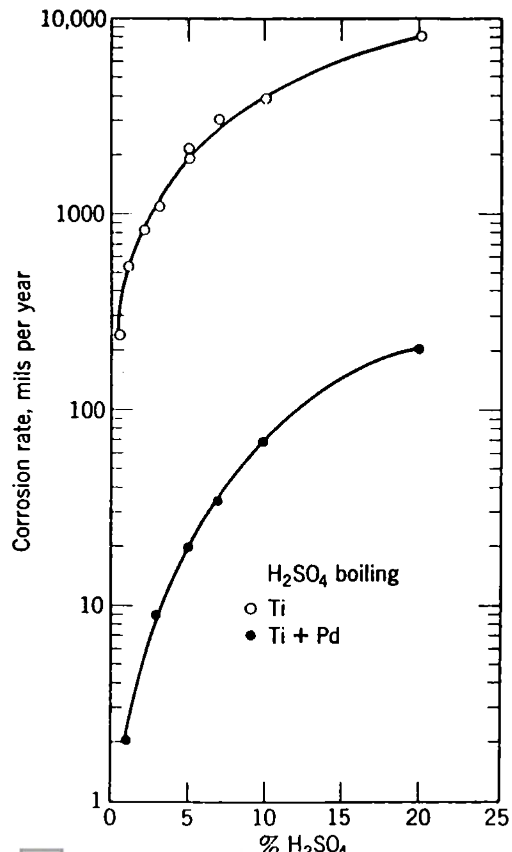
Zirconium. Comparison of pitting potential of Zr705, as determined by the scratch method, potentiodynamic method, and the potentiostep method. Source: J.S. Chen, A. Bronson, *et al.*, "Pitting Corrosion on Zirconium in KCl and KCl-H_2SO_4 Solutions," *Corrosion*, Vol 41, Aug 1985, 441.



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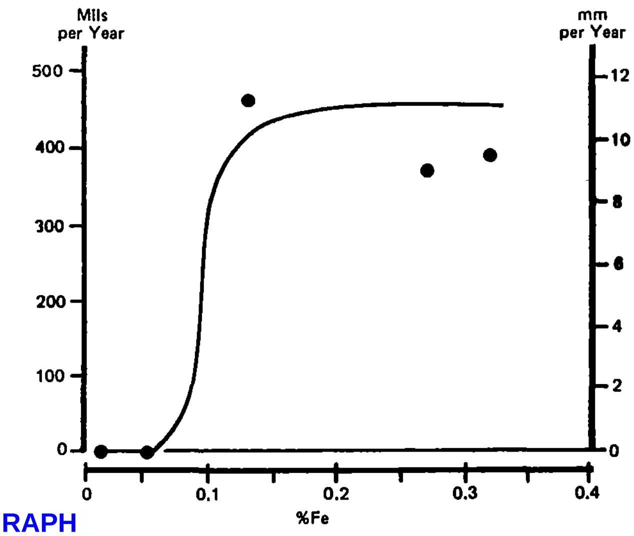
Titanium. Comparison of titanium and Ti-0.20Pd alloy in boiling sulfuric acid. Source: H. Godard, W. Jepson, *et al.*, *The Corrosion of Light Metals*, John Wiley & Sons, New York, 1976.



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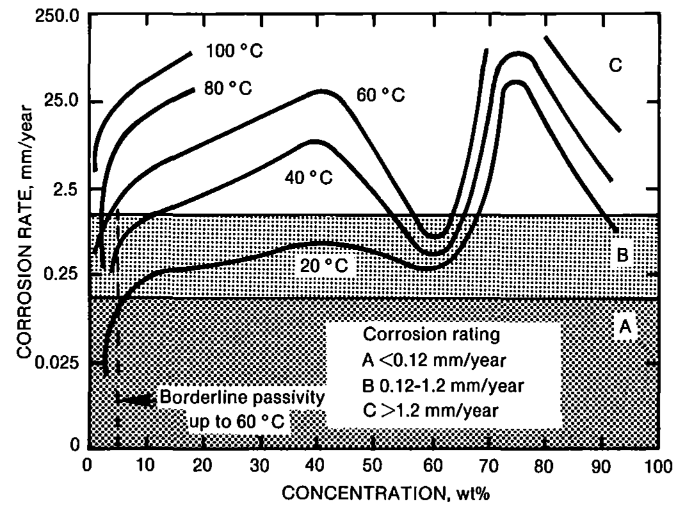
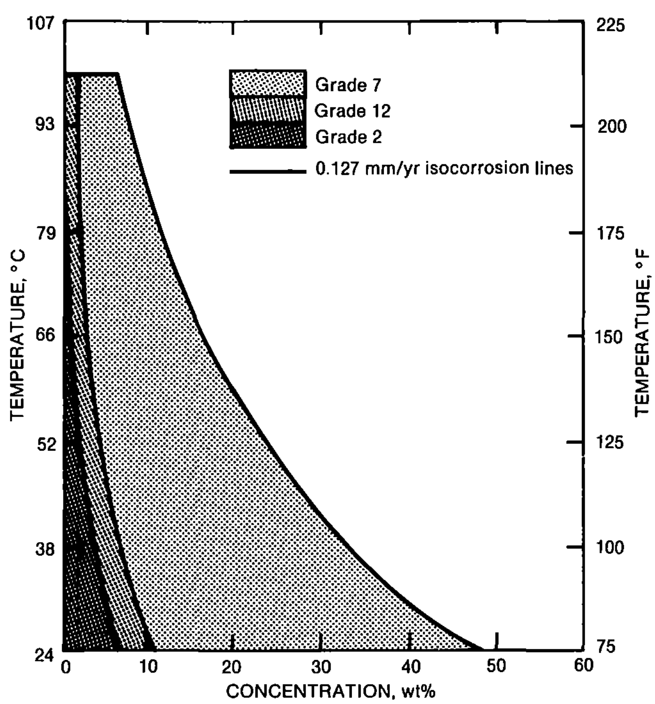
Titanium. Effect of iron content of CP titanium on corrosion rate in boiling 1% sulfuric acid. Source: RMI Titanium Company, 1982.



Titanium. Corrosion rate of titanium in sulfuric acid solutions (natural aeration). Source: Imperial Metal Industries (Kynoch) Ltd.



Titanium. Isocorrosion diagram for titanium alloys in pure, naturally aerated sulfuric acid solutions. The 0.127 mm/yr (5 mils/yr) isocorrosion lines are shown. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 680.

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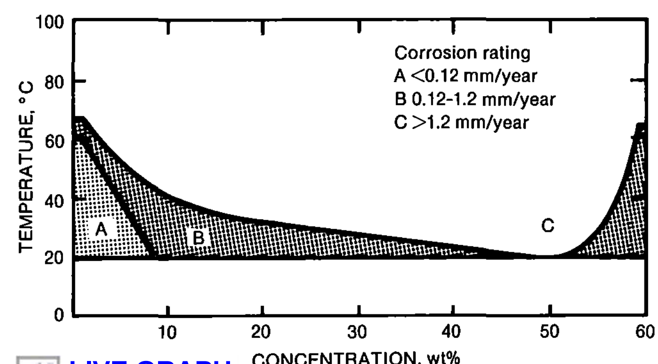

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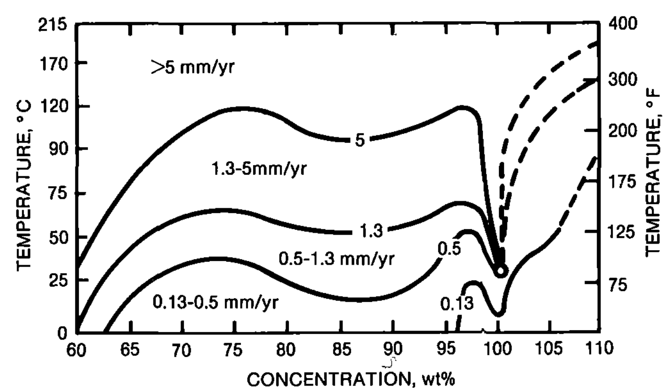
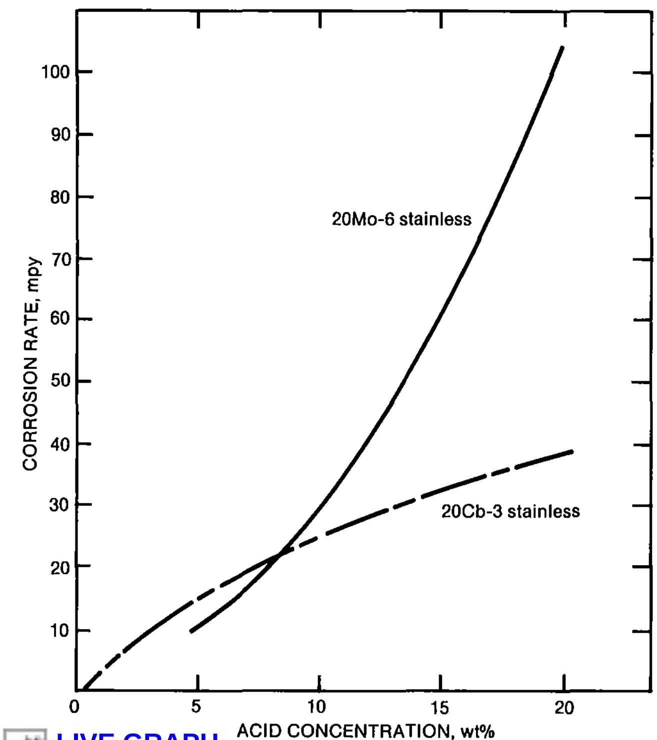
Titanium. Isocorrosion chart for titanium in sulfuric acid (natural aeration). Source: Imperial Metal Industries (Kynoch) Ltd.



Steel. Corrosion of steel by sulfuric acid as a function of temperature and acid concentration. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1149.



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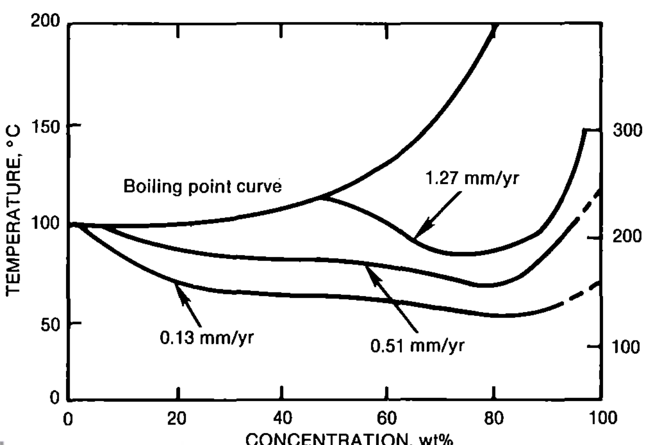
Stainless steel. Typical corrosion resistance of Carpenter 20Mo-6 in boiling reagent grade sulfuric acid. Source: Carpenter Technology, 1987.



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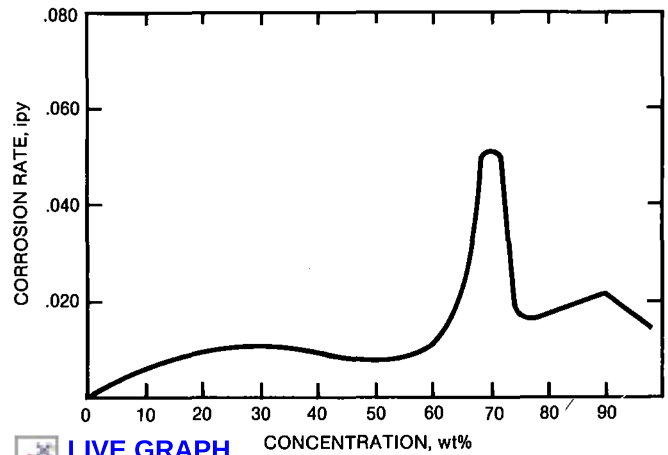
Stainless steel. Isocorrosion diagram for ACI CN-7M in sulfuric acid. Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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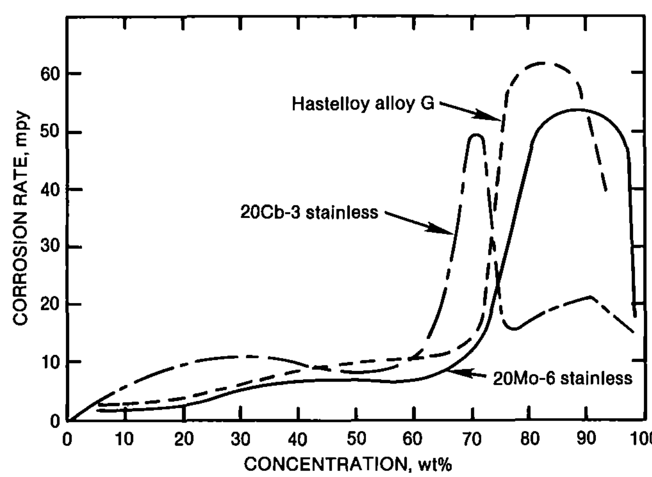
Stainless steel. Corrosion of 20Cb-3 in nonaerated sulfuric acid at 80 °C (176 °F). Source: Carpenter Technology, 1977.



Stainless steel. Typical isocorrosion chart to 20Mo-6 stainless in nonaerated sulfuric acid. Source: Carpenter Technology, 1987.

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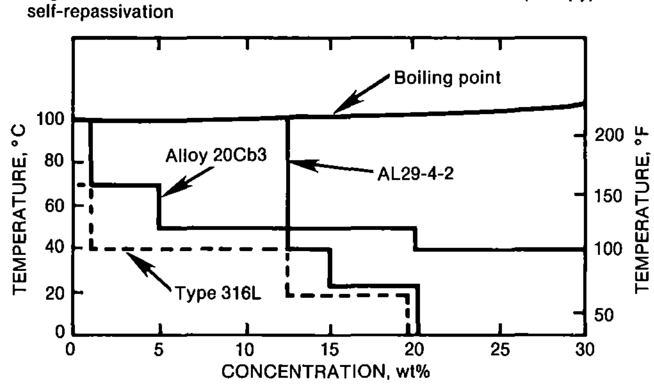
Regions outlined exhibit corrosion rates less than .25 mm/a (10 mpy) and self-repassivation



Stainless steel. Comparison of corrosion resistance of AL29-4-2, 20Cb-3, and type 316L stainless steel in sulfuric acid. Source: Allegheny Ludlum Corporation, 1982.

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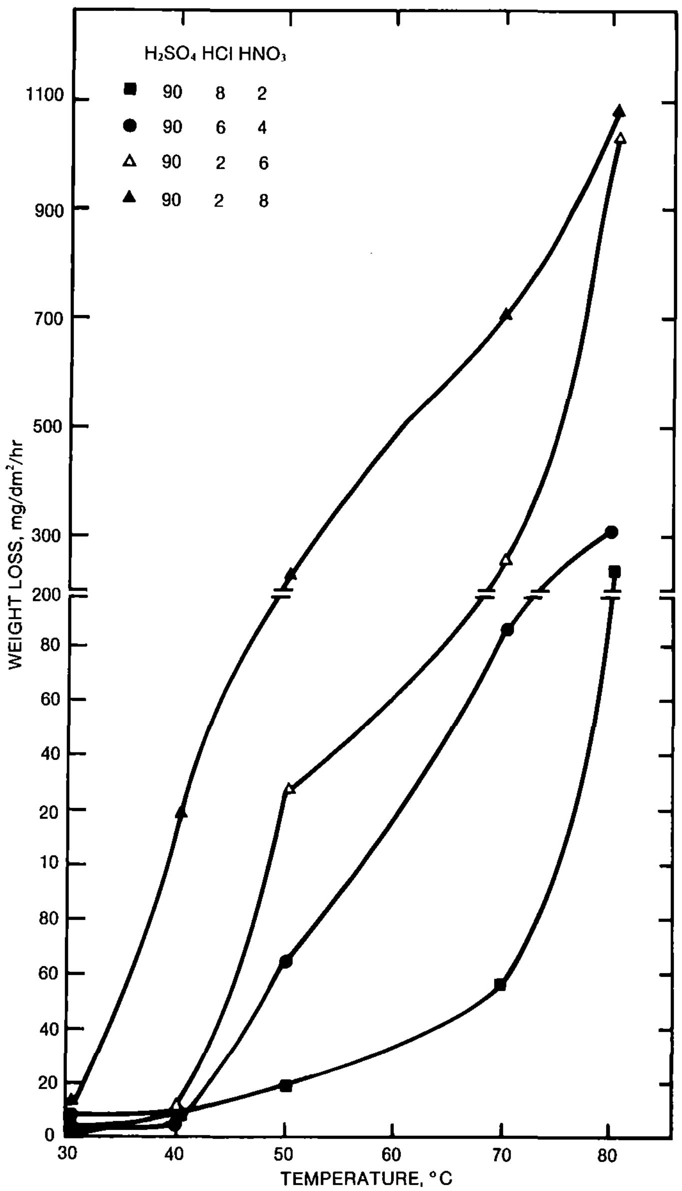
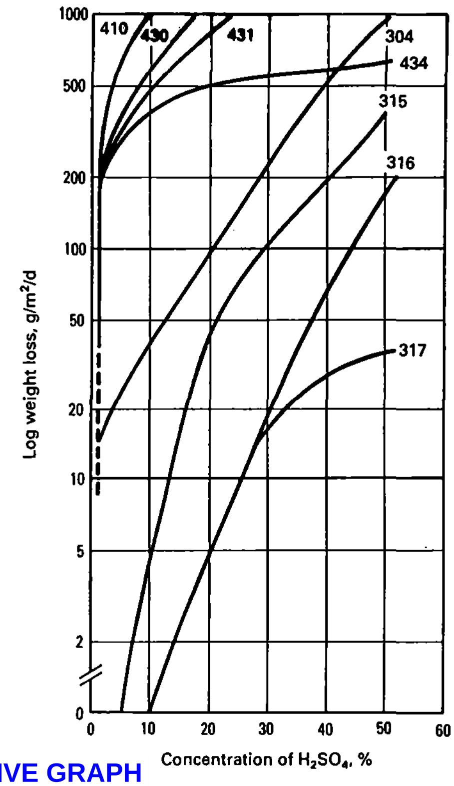


Stainless steel. Effect of temperature on corrosion of AISI 304 stainless steel immersed in ternary mixture of hydrochloric acid, sulfuric acid, and nitric acid. Source: M. Vajpeyi, S. Gupta, *et al.*, "Corrosion of Stainless Steel (AISI 304) in Sulfuric Acid Contaminated with HCl and HNO_3," *Corrosion Prevention and Control*, Vol 32, Oct 1985, 104.



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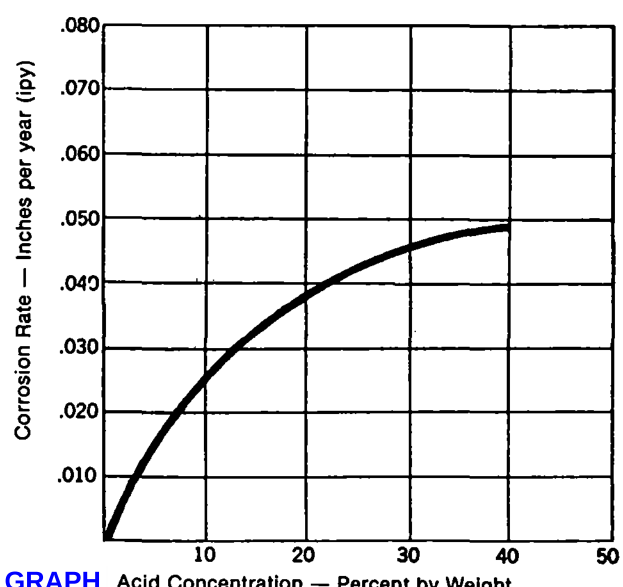
Stainless steel. Corrosion rates of various stainless steels in unaerated sulfuric acid at 20 °C (70 °F). Source: J.E. Truman, in *Corrosion: Metal-Environment Reactions*, Vol 1, L.L. Shreir, Ed., Newness-Butterworths, 1976, 352.



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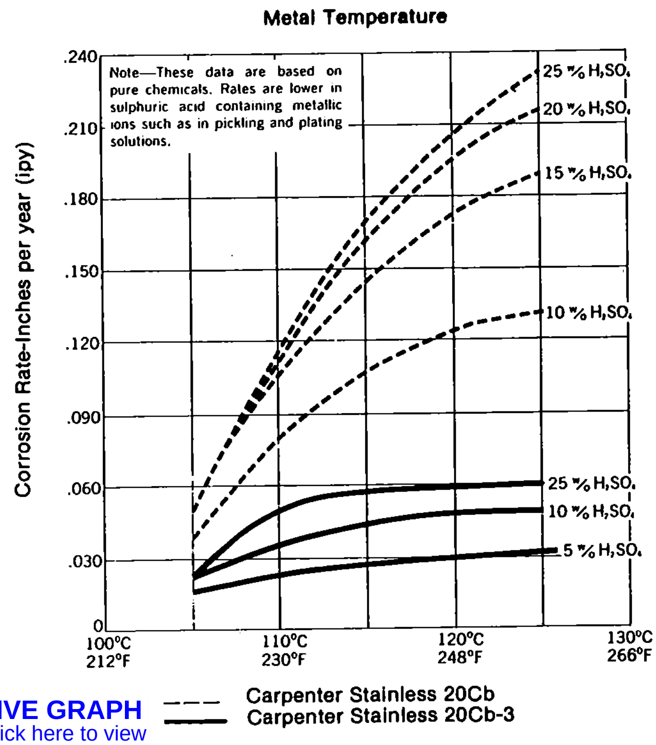
Stainless steel. Corrosion rate of 20Cb-3 vs. concentration of boiling sulfuric acid. Source: Carpenter Technology, 1977.



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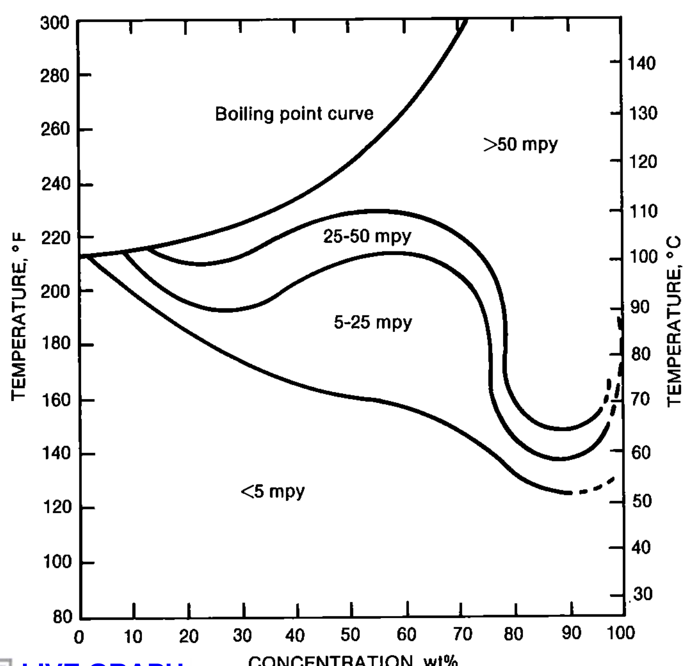
Stainless steel. Corrosion of annealed 20Cb and improved 20Cb-3 to boiling sulfuric acid as a function of metal temperature and concentration. Source: Carpenter Technology, 1977.



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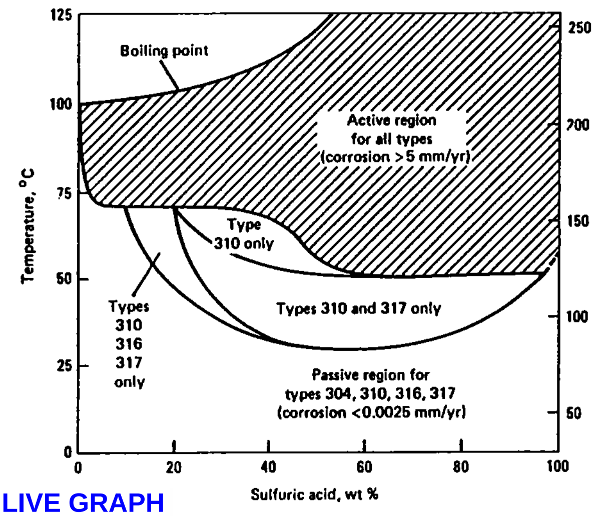
Stainless steel. Typical isocorrosion chart for 20Mo-6 stainless in nonaerated sulfuric acid. Source: Carpenter Technology, 1987.



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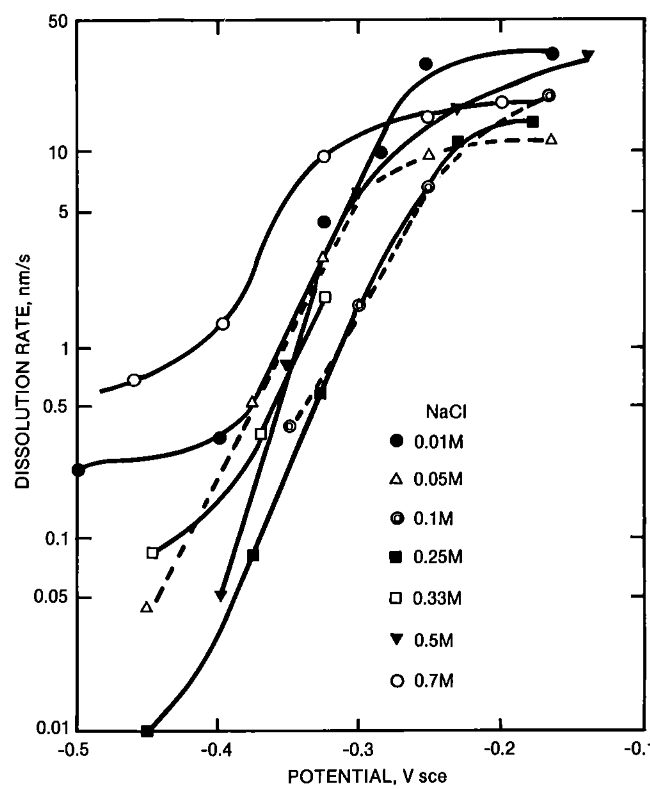
Stainless steel. Active and passive corrosion regions for stainless steels in aerated sulfuric acid solutions. Source: *Metals Handbook*, 9th ed., Vol 3, Properties and Selection: Stainless Steels, Tool Materials, and Special-Purpose Metals, American Society for Metals, Metals Park, OH, 1980, 91.



Stainless steel. Average (uniform) dissolution rate potential curves for AISI 304 obtained from the weight loss in 2*M* H_2SO_4-NaCl for 30-min exposure at 90 °C. Source: M. Asawa, "Stress Corrosion Cracking Regions

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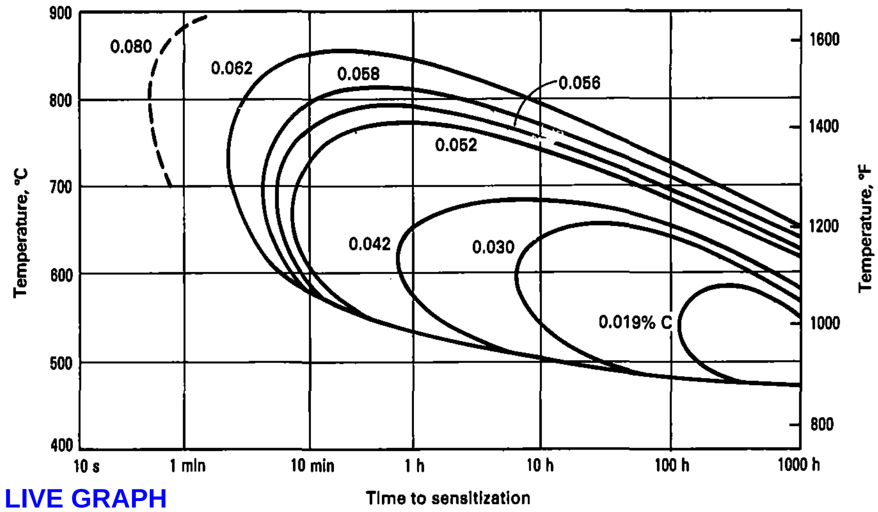

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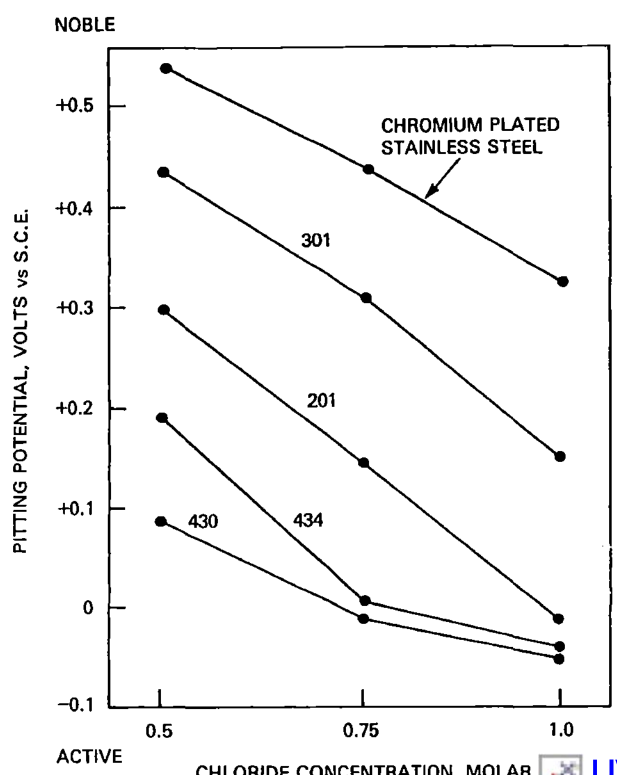
Stainless steel. Time-temperature-sensitization curves for type 304 stainless steel in a mixture of $CuSO_4$ and H_2SO_4 containing free copper. Curves show the times required for carbide precipitation in steels with various carbon contents. Carbides precipitate in the areas to the right of the various carbon content curves. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 551.



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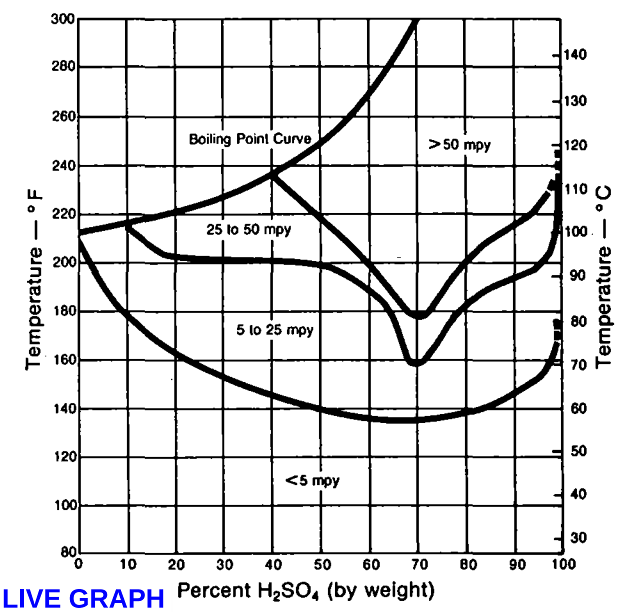
Stainless steel. Effect of chloride concentration on the pitting potential of various stainless steels in sulfuric acid solution containing chloride at the levels indicated. Source: A.J. Sedriks, "Effects of Alloy Composition and Microstructure on the Passivity of Stainless Steels," *Corrosion*, Vol 42, July 1986, 378.



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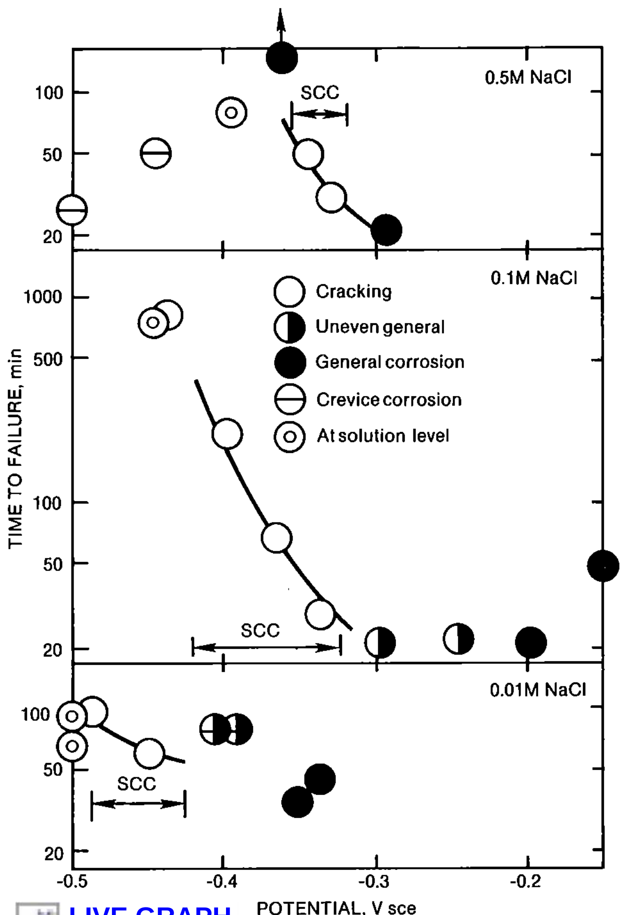
Stainless steel. Isocorrosion chart for 20Cb-3 in sulfuric acid. Source: Carpenter Technology, 1977.



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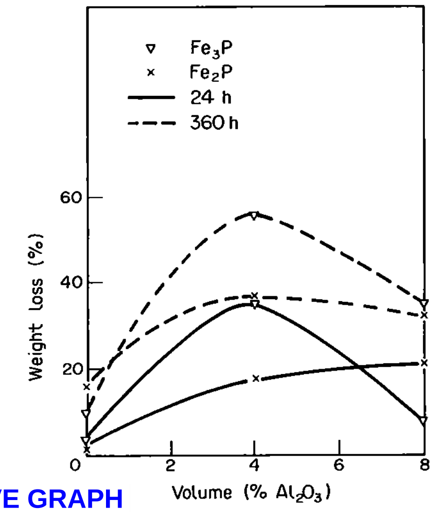
Stainless steel. Effects of potential and NaCl concentration on time to fracture and the fracture mode on AISI 304 in 2*M* H_2SO_4-NaCl solution at 95 °C at a constant load of 225 N (initial stress of 324 MPa). The double circles and circles with horizontal lines represent fracture by local corrosion at the testing solution (air interface) and by crevice corrosion in the rubber plug, respectively. Source: M. Asawa, "Stress Corrosion Cracking Regions on Contour Maps of Dissolution Rates for AISI 304 Stainless Steel in Sulfuric Acid Solutions with Chloride, Bromide, or Iodide," *Corrosion*, Vol 43, April 1987, 199.



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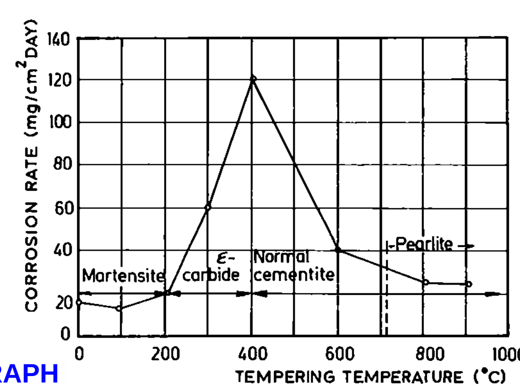
Stainless steel. Percentage weight loss of 0.5 wt% P (either as Fe_3P or Fe_2P) in 1*N* sulfuric acid at room temperature for different periods. Source: S.K. Mukherjee, G.S. Upadhyaya, "Corrosion Behaviour of Sintered 434L Ferritic Stainless Steel, Al_2O_3 Composites Containing Phosphorus," *Corrosion Science*, Vol 25, Sept 1985, 464.



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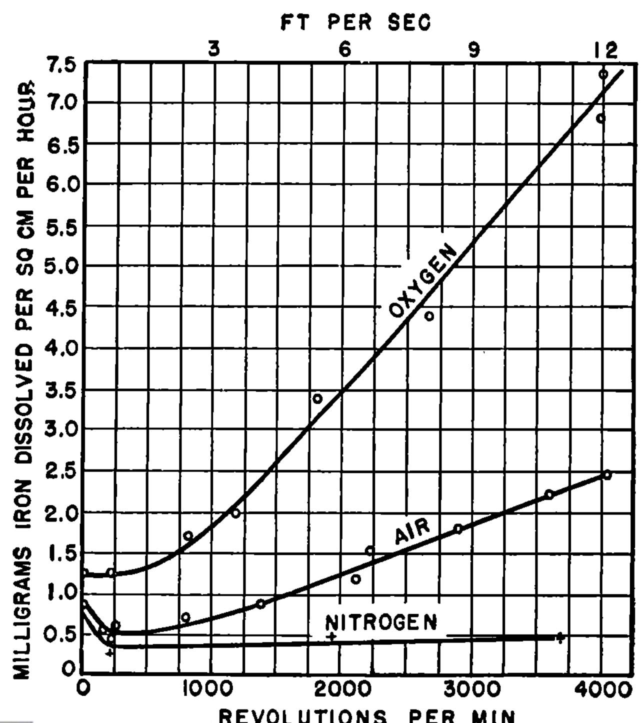
Steel. Effect of heat treatment on corrosion of 0.95% carbon steel in 1% sulfuric acid. Specimen area 18.5 cm^2; specimen weight 29 g; tempering time 2 h. Source: G. Wranglen, *An Introduction to Corrosion and Protection of Metals*, Chapman Hall, New York, 1985, 73.



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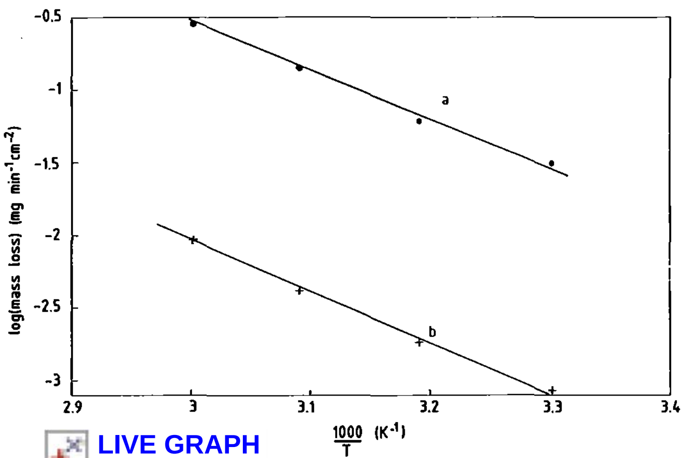
Steel. Effect of velocity on corrosion of mild steel (0.12% carbon) in 0.33*N* sulfuric acid under air, oxygen or nitrogen. Source: H.H. Uhlig, "Iron and Steel," in *The Corrosion Handbook*, H.H. Uhlig, Ed., John Wiley & Sons, New York, 1948, 137.



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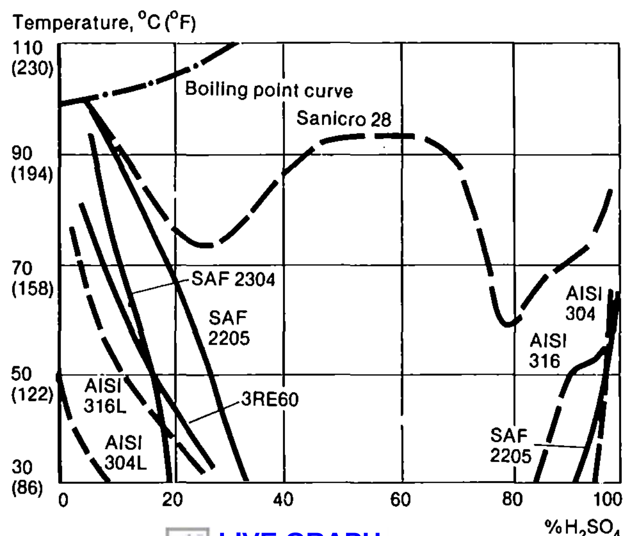
Steel. Arrhenius plot of the corrosion rate of steel in 2.5*N* sulfuric acid (a) in the absence and (b) in the presence of 1 x 10^{-3} M compound IV. Compound IV = 4-amino-3-phenyl-5-mercapto-1,2,4-triazoline. Source: B. Abd-El-Nabey, A. El-Toukhy, *et al.*, "4-Amino-3-Substituted-5-Mercapto-1,2,4-Triazolines as Inhibitors for the Acid Corrosion of Steel," *Surface Coating Technology*, Vol 27, April 1986, 333.



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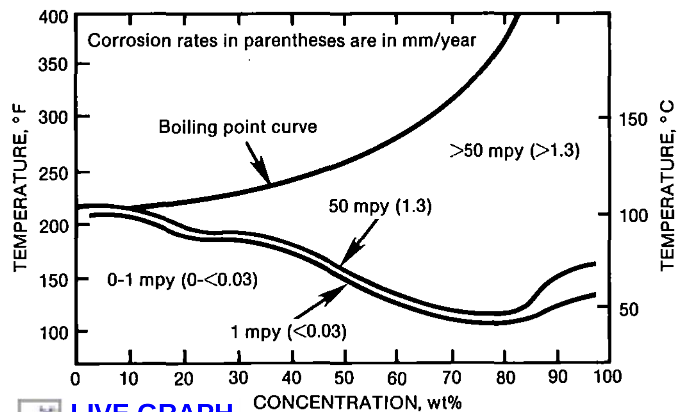
Duplex stainless steel. Isocorrosion diagram for duplex and austenitic stainless steels in stagnant sulfuric acid in contact with air. At the curves, the corrosion rate is 0.3 mm/yr. Source: S. Bernhardsson, P. Norberg, *et al.*, "Stainless Steels in the Petrochemical Industries," *Iron and Steel International*, Vol 58, Feb 1987, 8.



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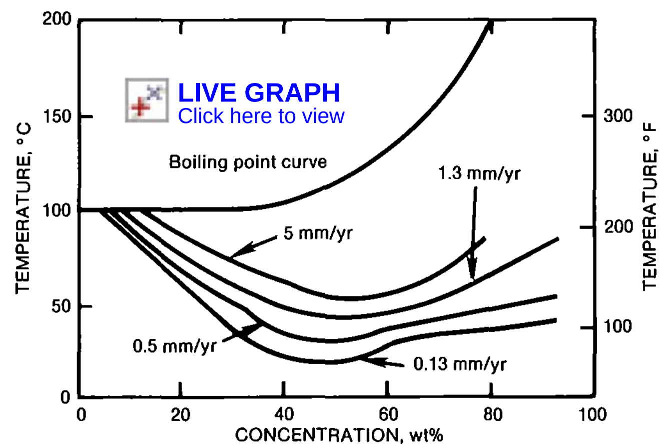
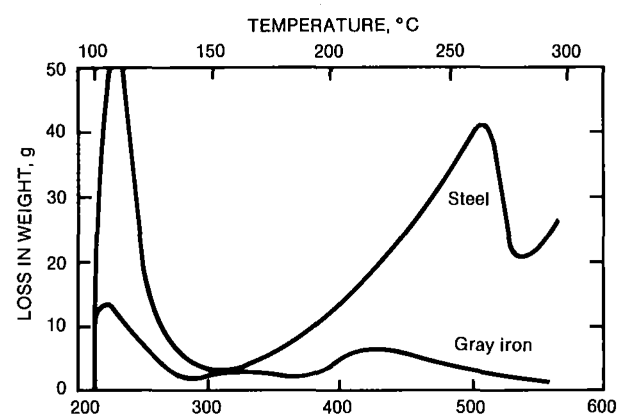
Duplex stainless steel. Corrosion resistance of Hastelloy alloy 255 and Ferralium to sulfuric acid. Source: Haynes International, 1987.



Duplex stainless steel. Isocorrosion diagram for ACI CD-4MCu in sulfuric acid. Source: *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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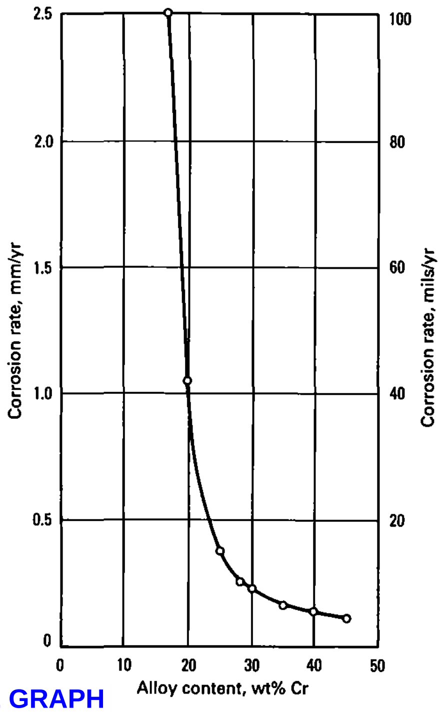
Gray iron. Corrosion of gray iron and steel by sulfuric acid at temperatures up to 315 °C (600 °F). Source: C. Walton, T. Opar, *Iron Castings Handbook*, Iron Castings Society, 1981, 507.



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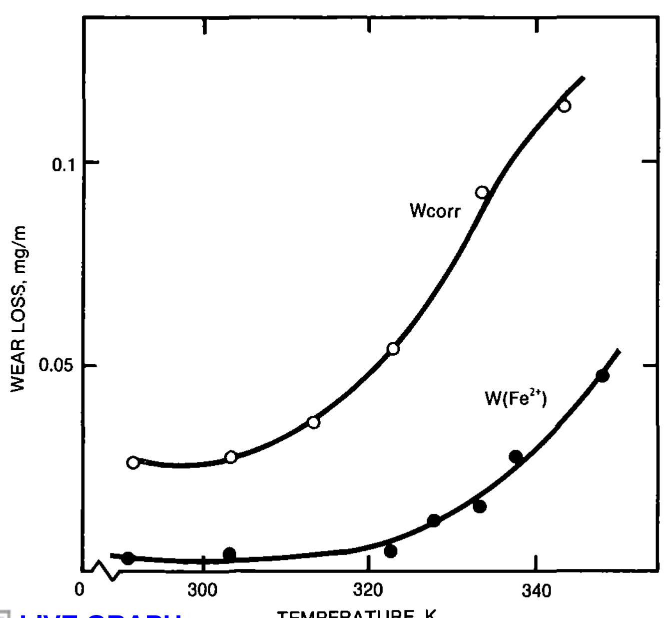
Iron-chromium alloys. The effect of chromium content on the corrosion behavior of iron-chromium alloys in boiling 50% sulfuric acid with $Fe_2(SO_4)_2$. Source: R.F. Steigerwald, *Metallurgical Transactions*, Vol 5, 1974, 2265-2269.



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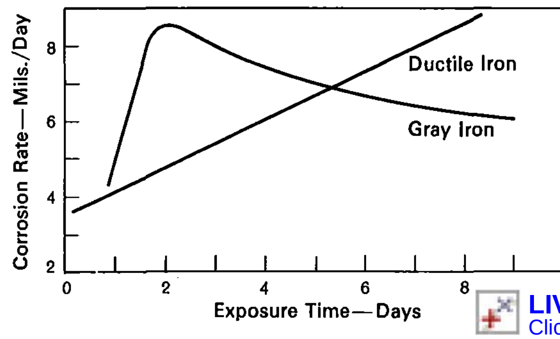
Cast iron. Wear loss and the effect of temperature in 65% sulfuric acid at 0.13 m/s and 1.7 MPa. Source: Y. Yahagi and Y. Mizutani, "Corrosive Wear of Cast Iron in Sulphuric Acid," *Journal of Tribology*, Vol 109, April 1987, 238-242.



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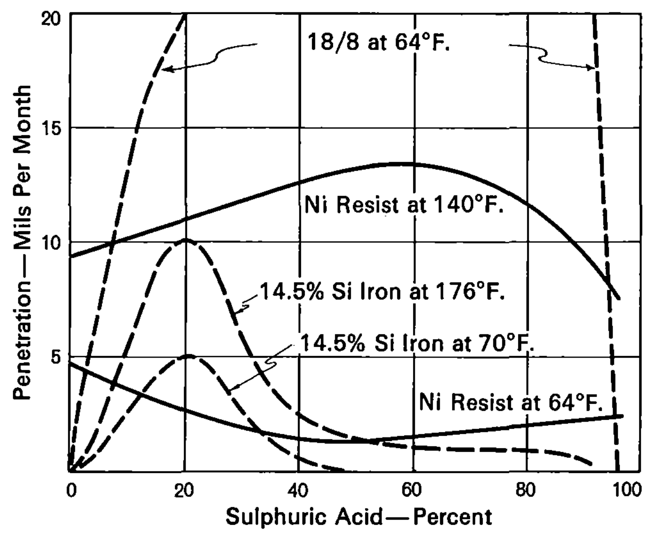
Iron. Effect of exposure time on the corrosion rate in 0.5% sulfuric acid at room temperature. Source: "Physical and Corrosion Properties," in *Source Book on Ductile Iron*, A.H. Rauch, Ed., American Society for Metals, Metals Park, OH, 1977, 363.



Iron. Corrosion rates of nickel and silicon high alloy irons at selected temperatures compared to 18-8 stainless steel in different concentrations of sulfuric acid. Source: "Physical and Corrosion Properties," in *Source Book on Ductile Iron*, A.H. Rauch, Ed., American Society for Metals, Metals Park, OH, 1977, 366.

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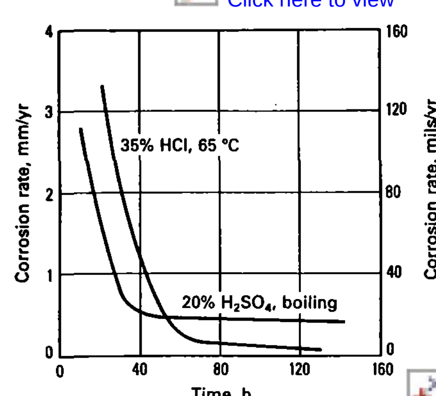

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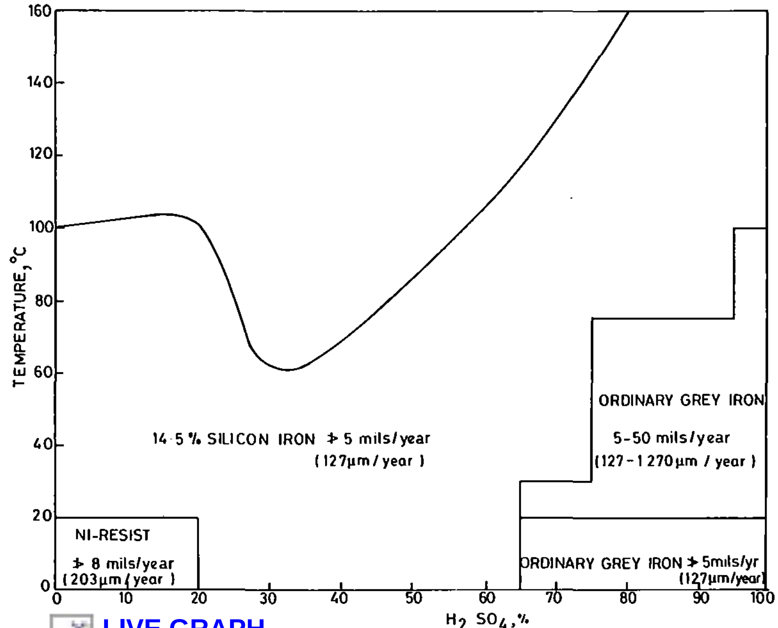
Cast iron. Corrosion rates of high-silicon cast irons as a function of time and media. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 567.



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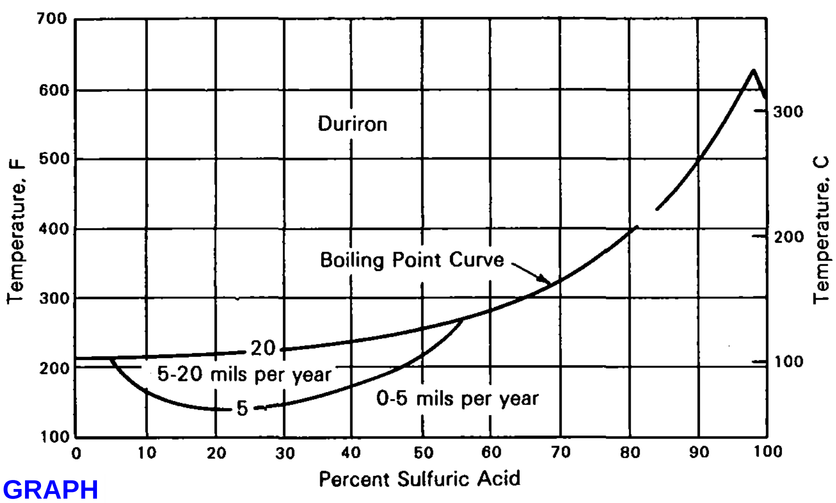
Cast iron. Corrosion rates of cast iron in sulfuric acid. Source: H.T. Angus, *Cast Iron: Physical and Engineering Properties,* 2nd ed., Butterworths, London, 1976, 313.



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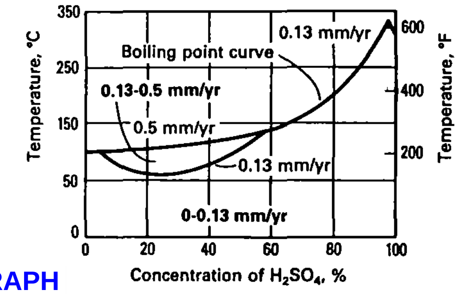
Cast iron. Effect of concentration and temperature on corrosion of high-silicon cast iron by sulfuric acid. Source: C. Walton and T. Opar, *Iron Castings Handbook*, Iron Castings Society, 1981, 510.



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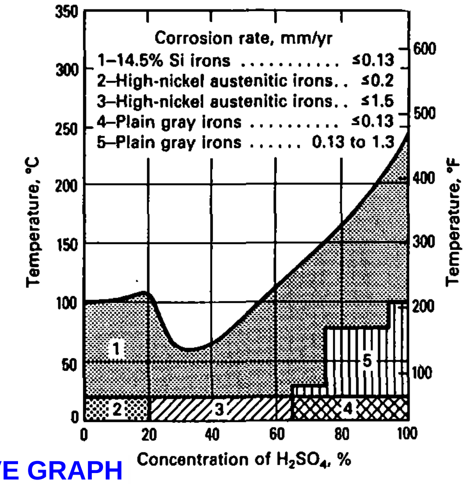
Cast iron. Corrosion by sulfuric acid as a function of temperature and acid concentration. Source: "The Corrosion Resistance of Nickel-Containing Alloys in Sulfuric Acid and Related Compounds," *Corrosion Engineering Bulletin 1*, The International Nickel Company, 1983.



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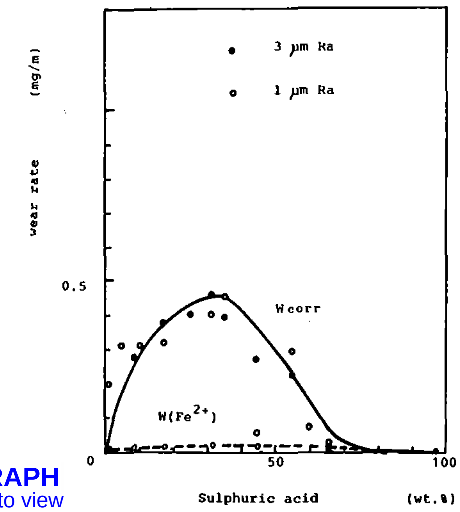
Cast iron. Corrosion of high-nickel austenitic cast iron in sulfuric acid as a function of acid concentration and temperature. Source: E.C. Miller, *Liquid Metals Handbook*, 2nd ed., Government Printing Office, Washington, DC, 1952, 144.



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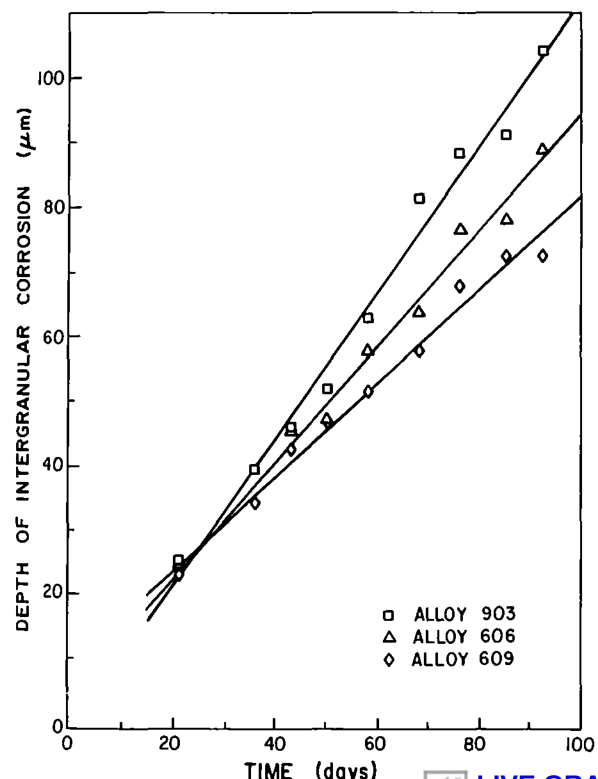
Cast iron. Wear loss of cast iron with different surface roughness (1 μm Ra and 3 μm Ra) in sulfuric acid, 0.13 m/s, 1.7 MPa, and 291 K. Source: Y. Yahagi and Y. Mizutani, "Corrosive Wear of Cast Iron in Sulphuric Acid," *Journal of Tribology*, Vol 109, April 1987, 239.



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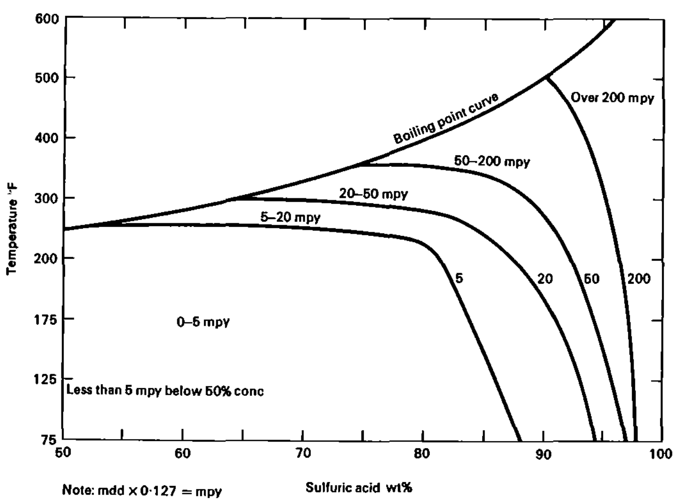
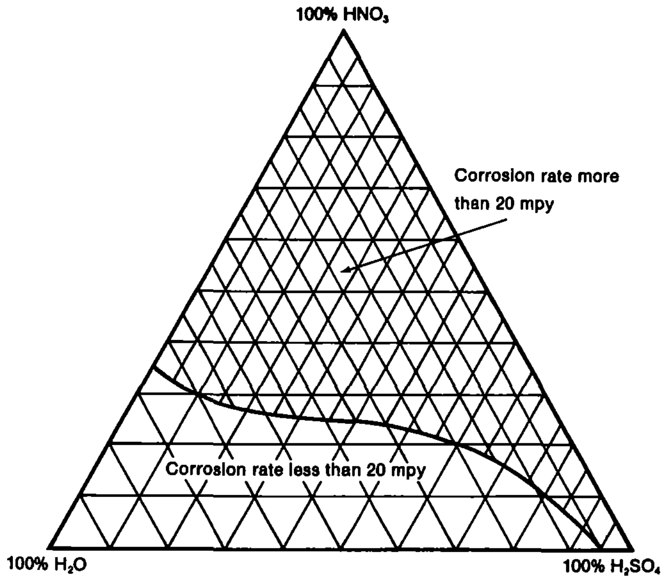
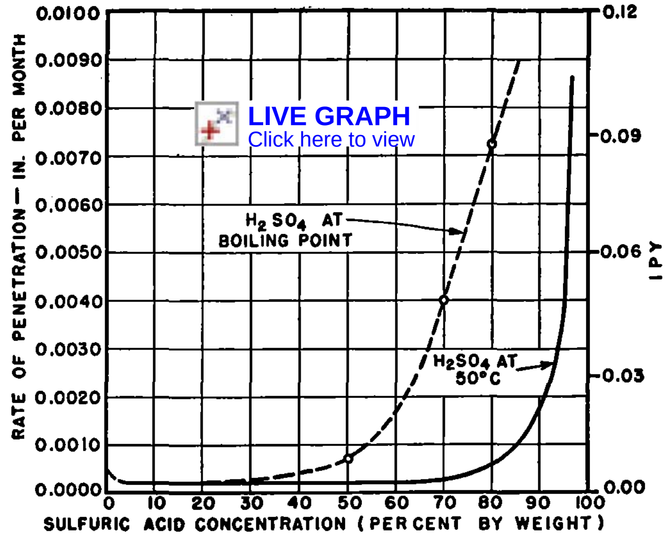
Lead alloy. Depth of intergranular corrosion as a function of time. The rate of intergranular corrosion decreases with increasing tin to calcium ratio and/or increasing tin content. Corrosion testing was carried out at 50 °C in 1.27 (+0.02) specific gravity sulfuric acid, at a constant anodic overpotential of 200 mV. Source: D. Kelly, P. Niessen, *et al.*, "The Influence of Composition and Microstructure on the Corrosion Behavior of Pb-Ca-Sn Alloys in Sulfuric Acid Solutions," *Journal of The Electrochemical Society*, Vol 132, Nov 1985, 2535.



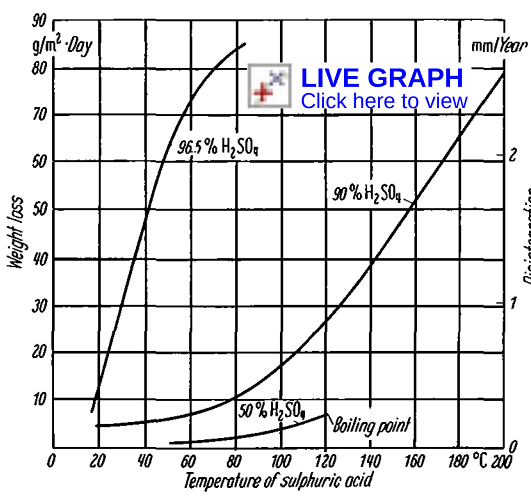
Lead. Corrosion resistance of lead in sulfuric acid. Source: *Lead for Corrosion Resistant Applications: A Guide*, Lead Industries Association, New York.



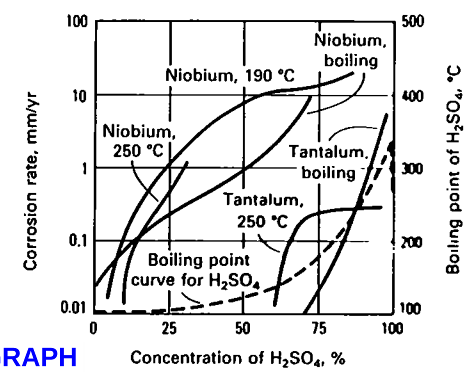
Lead. Corrosion rate of lead in mixed acids. Source: *Lead for Corrosion Resistant Applications: A Guide*, Lead Industries Association, New York.



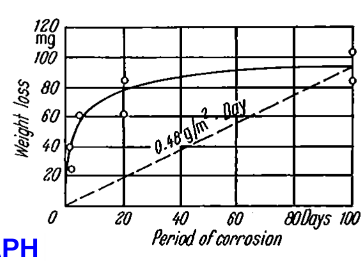
Lead. Corrosion of lead in sulfuric acid. The specimens were removed daily for 14 days and the protective sulfate coating was dissolved in acidified ammonium acetate solution (5%, hot). The corrosion rates are maximums for total immersion in sulfuric acid. Although these values are excessively high, they serve as a guide for commercial practice. Source: G.O. Hiers, "Lead and Lead Alloys," in *The Corrosion Handbook*, H.H. Uhlig, Ed., John Wiley & Sons, New York, 1948, 212.



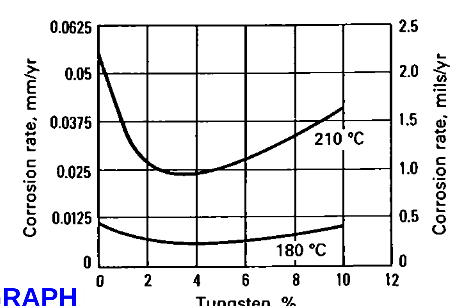
Lead. Effect of temperature and concentration on corrosion of lead in sulfuric acid. Source: W. Hofmann, *Lead and Lead Alloys: Properties and Technology*, G. Vibrans, Ed., Springer-Verlag, New York, 1970, 274.



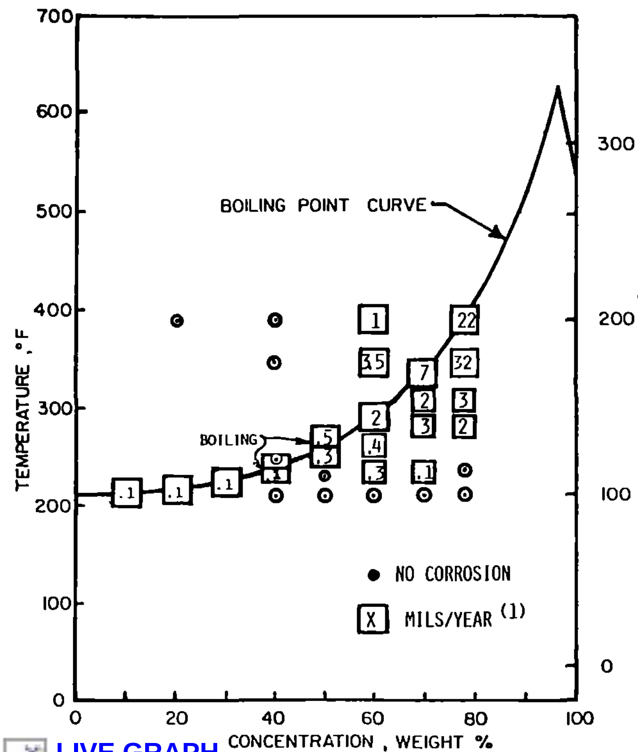
Niobium and tantalum. Corrosion of niobium and tantalum in sulfuric acid at various concentrations and temperatures. Source: C.R. Bishop, *Corrosion*, Vol 14, 1963, 308.



Lead. Course of corrosion vs. time of lead in 80% sulfuric acid at room temperature. Source: W. Hofmann, *Lead and Lead Alloys: Properties and Technology*, G. Vibrans, Ed., Springer-Verlag, New York, 1970, 273.



Tantalum-tungsten alloy. Corrosion rate vs. tungsten content for tantalum-tungsten alloys exposed to concentrated sulfuric acid at 180 °C (360 °F) and 210 °C (405 °F). Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 736.



LIVE GRAPH
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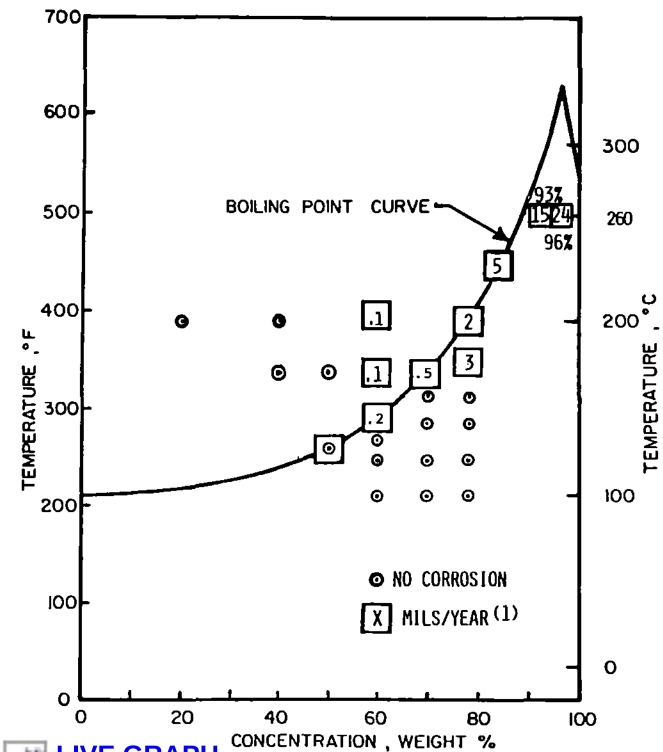
Tantalum. Corrosion resistance of KBI alloy 40 in sulfuric acid. KBI alloy 40 is a Ta-40Nb alloy. Source: R.H. Burns, F.S. Shuker, Jr., *et al.*, "Industrial Applications of Corrosion-Resistant Tantalum, Niobium, and Their Alloys," in *Refractory Metals and Their Industrial Applications* (STP 849), R.E. Smallwood, Ed., ASTM, Philadelphia, 1984, 63.



LIVE GRAPH
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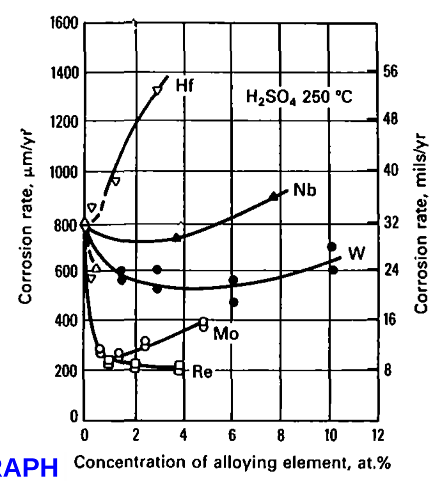
Tantalum. Corrosion resistance of tantalum in sulfuric acid. Source: R.H. Burns, F.S. Shuker, Jr., *et al.,* "Industrial Applications of Corrosion-Resistant Tantalum, Niobium, and Their Alloys," in *Refractory Metals and Their Industrial Applications* (STP 849), R.E. Smallwood, Ed., ASTM, Philadelphia, 1984, 62.



LIVE GRAPH
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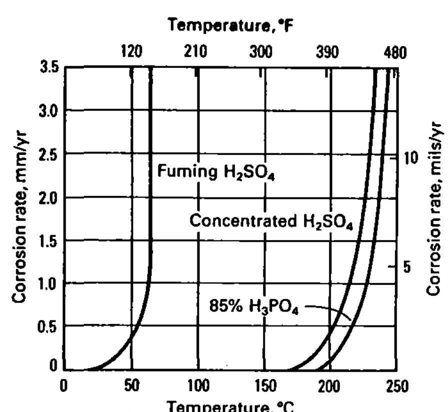
Tantalum alloy. Influence of alloying elements on the corrosion rate of binary tantalum alloys exposed 3 days to 95% sulfuric acid at 250 °C (480 °F). Source: L.A. Gypen, M. Brabers, and A. Deruyttere, "Corrosion Resistance of Tantalum Base Alloys, Elimination of Hydrogen Embrittlement in Tantalum by Substitutional Alloying," *Werkstoffe und Korrosion*, Vol 35, 1984, 37-46.



LIVE GRAPH
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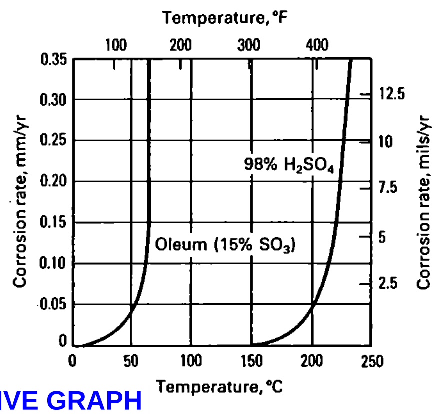
Tantalum. Corrosion rates of tantalum in fuming sulfuric acid (oleum) and concentrated sulfuric acid. Source: D.F. Taylor, "Tantalum: Its Resistance to Corrosion," Paper presented at the Chicago Section, The Electrochemical Society, May 1956.



LIVE GRAPH
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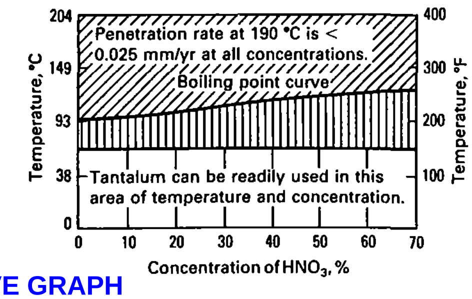
Tantalum. Corrosion of tantalum in 98% sulfuric acid and in oleum. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1154.



LIVE GRAPH
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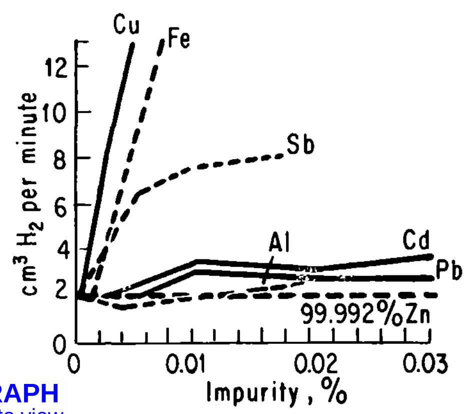
Tantalum. Corrosion resistance of tantalum in sulfuric acid. Source: R.H. Burns, F.S. Shuker, Jr., *et al.*, "Industrial Applications of Corrosion-Resistant Tantalum, Niobium and Their Alloys," in *Refractory Metals and Their Industrial Applications* (STP 849), R.E. Smallwood, Ed., ASTM, Philadelphia, 1984, 62.



LIVE GRAPH
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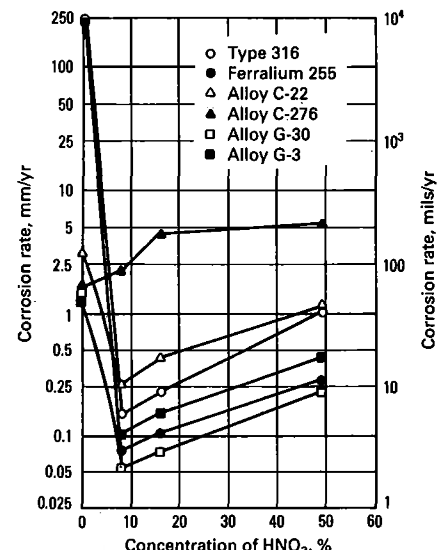
Zinc. Effect of impurities on the corrosion rate of zinc in dilute (18 g/L) sulfuric acid at room temperature. Original purity of the zinc was 9.982%. Source: N.D. Tomashov, *Theory of Corrosion and Protection of Metals*, B. Tytell, I. Geld, *et al.*, Ed., McMillan, New York, 1966, 633.



LIVE GRAPH
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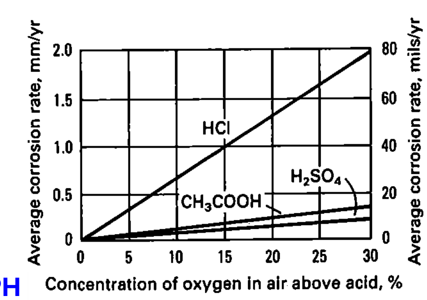
Various alloys. Effect of HNO_3 on the corrosion of various alloys in a boiling 30% sulfuric acid solution. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 649.



LIVE GRAPH
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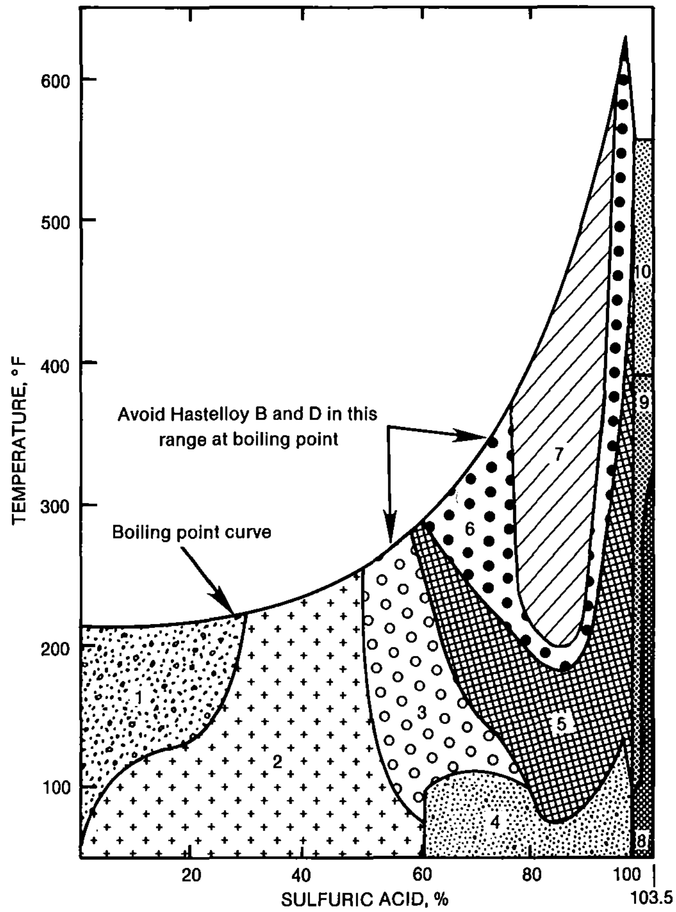
Copper. Effect of oxygen on corrosion rates for copper in 1.2*N* solutions of nonoxidizing acids. Specimens were immersed for 24 h at 24 °C (75 °F). Oxygen content of the solutions varied from test to test, depending on the concentration of oxygen in the atmosphere above the solutions. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 627.



CODE FOR SULFURIC ACID CHART

ZONE 1

Impervious graphite
Tantalum
Gold
Platinum
Silver
Zirconium
Nionel
Tungsten
Molybdenum
Type 316 stainless (up to 10% aerated)

10% aluminum bronze (air free)
Illium G
Glass
Hastelloy B and D
Durimet 20
Worthite
Lead
Copper (air free)
Monel (air free)
Haveg 43
Rubber (up to 170 °F)

ZONE 2

Ni-Resist (up to 20%)
Impervious graphite
Tantalum
Gold
Platinum
Silver
Zirconium
Nionel
Tungsten
Molybdenum
Type 316 stainless (up to 25% at 75 °F) aerated

Glass
Silicon iron
Hastelloy B and D
Durimet 20 (up to 150 °F)
Worthite (up to 150 °F)
Lead
Copper (air free)
Monel (air free)
Haveg 43
Rubber (up to 170 °F)
10% aluminum bronze (air free)

ZONE 3

Impervious graphite
Tantalum
Gold
Platinum
Zirconium
Molybdenum

Glass
Silicon iron
Hastelloy B and D
Durimet 20 (up to 150 °F)
Worthite (up to 150 °F)
Lead Monel (air free)

ZONE 4

Ni-Resist
Type 316 stainless (above 80%)
Impervious graphite (up to 96% H_2SO_4)
Tantalum
Gold
Platinum
Zirconium

Steel
Glass
Silicon iron
Hastelloy B and D
Lead (up to 96% H_2SO_4)
Durimet 20 Worthite

ZONE 5

Lead (up to 175 °F and 96% H_2SO_4)
Impervious graphite (up to 175 °F and 96% H_2SO_4)
Tantalum
Gold
Platinum

Glass
Silicon iron
Hastelloy B and D
Durimet 20 (up to 150 °F)
Worthite (up to 150 °F)

ZONE 6

Tantalum
Gold
Platinum

Glass
Silicon iron
Hastelloy B and D (20-50 mpy)

ZONE 7

Gold
Platinum

Glass
Silicon iron
Tantalum

ZONE 8

Worthite
Hastelloy C
Gold
Platinum

Glass
Steel 18 Cr-8 Ni
Durimet 20

ZONE 9

Worthite Gold Platinum

Glass 28 Cr-8 Ni Durimet 20

ZONE 10

Platinum
Glass Gold

Materials in shaded zones have a reported corrosion rate of less than 20 mpy

Various metals. Corrosion resistance of various metals to sulfuric acid. Corrosion rates are less than 20 mils/yr. Source: M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill, New York, 1986, 330.

Sulfurous Acid

Sulfurous acid, H_2SO_3, is an unstable, water-soluble, colorless liquid with a strong sulfur aroma. It is derived from absorption of sulfur dioxide (SO_2) in water. Reagent grade sulfurous acid contains about 6% sulfur dioxide in solution. Sulfurous acid is a strong reducing agent. It is readily oxidized to sulfuric acid and is itself reduced to hydrogen sulfide by zinc and dilute sulfuric acid. Sulfurous acid is used in the synthesis of medicines and chemicals, in the manufacture of paper and wine, in brewing, in metallurgy, in ore flotation, as a bleach and analytical reagent, and for refining of petroleum products.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Although sulfurous acid is a reducing agent, several stainless steels have provided satisfactory service in sulfurous acid environments. Conventional austenitic stainless steels have been used in sulfite digestors, and types 316 and 317 stainless steels, 20Cb-3, and cast ACI CF-8M and CN-7M stainless steels have been used in wet sulfur dioxide and sulfurous acid environments. Service life is improved by eliminating crevices, including those from settling of suspended solids, or by using molybdenum-containing grades. In some environments, stress-corrosion cracking is also a possibility.

Aluminum. In laboratory tests, dilute aqueous solutions of sulfurous acid caused corrosion of alloy 1100, which increased with concentration. At 0.1% sulfurous acid, the attack was mild (~4 mils/yr), whereas at 8% the attack was moderate (~12 mils/yr). Sulfurous acid condensed from gases containing sulfur dioxide and moisture will cause corrosion of aluminum alloys.

Lead. Lead has high corrosion resistance to sulfurous acid. It performs well at acid concentrations up to 95% at ambient temperatures, up to 85% at 220 °C (428 °F), and up to 93% at 150 °C (302 °F). Below a concentration of 5%, the corrosion rate increases, but it is still relatively low. Lead exhibits the same excellent corrosion resistance to higher concentrations of sulfurous acid at elevated temperatures.

Nickel. A wide variety of nickel alloys are available for use in flue gas desulfurization applications. Incoloy 825 and Hastelloy G are significantly more corrosion resistant in sulfurous and sulfuric acids than austenitic stainless steels.

Niobium. Niobium is completely resistant in dilute sulfurous acid at 100 °C (212 °F). In concentrated acid at the same temperature, it has a corrosion rate of 0.25 mm/yr (10 mils/yr).

Tin. Tin is attacked by sulfurous acid.

Titanium. Titanium alloys exhibit good resistance to most mildly reducing acid solutions whether or not they are inhibited, including sulfurous acid. Near-nil corrosion rates can be expected over the full concentration range to temperatures well beyond the boiling point of sulfurous acid.

Corrosion Behavior of Various Metals and Alloys in Sulfurous Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	...	...	20 (68)	...	Resistant	...	92
Aluminum-manganese alloys	...	...	...	...	20 (68)	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Questionable	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Questionable	...	93
Admiralty brass	C44300	...	...	...	...	...	Good	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Good	...	93
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Questionable	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfurous Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Miscellaneous									
Gold	P00016	...	...	All	100 (212)	...	0.05 (2) max	...	8
High purity lead	L50001	...	3% SO_3	...	24 (75)	...	.03 (1)	...	254
Lead	L50045	...	With 3% SO_2	...	24 (75)	...	0.03 (1)	...	49
Magnesium	...	...	...	All	Room	...	Poor	...	119
Silver	P07010	...	...	All	90 (195)	...	0.05 (2) max	...	4
Silver	P07010	...	...	All	90 (195)	...	0.05 (2) max	...	4
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet	Solutions were prepared with reagent-grade chemicals	5	80 (176)	7 d	1.1 (43)	...	44
Inconel 601	N06601	...	Average of two tests	6	80 (176)	7 d	1.4 (56)	Pitting attack	64
Inconel 690	N06690	...	...	6	80 (176)	...	1.1 (43)	...	57
Refractory metals and alloys									
Titanium	...	...	...	6	Room	...	Resistant	...	90
Zr702	R60702	...	...	6	Room	...	0.13 (5) max	...	15
Zr702	R60702	...	...	Saturated	192 (380)	...	1.3 (50) max	...	15
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
301	S30100	...	4 bar	...	135 (275)	...	Good	...	253
301	S30100	...	5-8 bar	...	160 (320)	...	Questionable	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
302	S30200	...	4 bar	...	135 (275)	...	Good	...	253
302	S30200	...	5-8 bar	...	160 (320)	...	Questionable	...	253
303	S30300	...	...	Saturated	20 (68)	...	Questionable	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
303	S30300	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
303	S30300	...	4 bar	...	135 (275)	...	Questionable	...	253
303	S30300	...	4 bar	...	135 (275)	...	Good	...	253
303	S30300	...	5-8 bar	...	160 (320)	...	Poor	...	253
303	S30300	...	5-8 bar	...	160 (320)	...	Questionable	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253
304	S30400	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
304	S30400	...	4 bar	...	135 (275)	...	Good	...	253
304	S30400	...	5-8 bar	...	160 (320)	...	Questionable	...	253
304	S30400	Annealed	All solutions from CP chemicals. Lab test	6	90 (194)	...	0.5 (18)	...	19
304	S30400	Annealed	All solutions from CP chemicals. Lab test	6	40 (104)	...	0.003 (0.1)	...	19
304	S30400	...	No aeration; no agitation. Dilute sulfurous acid, in propylene-glycol solution	...	26 (80)	30 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Sulfurous acid and caustic soda in varying concentrations, water effluent of air heater washing, pH 1.1-12.6	...	65 (150)	2.4 d	0.003 (0.1)	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfurous Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.3 d	25 (1000) min	...	89
304	S30400	Sensitized	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.3 d	25 (1000) min	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.1 d	7 (270)	Crevice attack	89
304	S30400	...	Slight to moderate aeration; rapid agitation; sensitized specimens. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.1 d	11 (430)	Crevice attack	89
304	S30400	...	Strong aeration; rapid agitation. Plus seawater, 1.7% sodium chloride	~2.05	13 (55)	30 d	0.04 (1.5)	Slight Pitting, crevice attack	89
304	S30400	...	Synthetic resin processing; no aeration; no agitation	~0.01	104 (219)	41.5 d	0.003 (0.1) max	...	89
304	S30400	...	Synthetic resin processing; no aeration; no agitation. With carbon over the standard maximum. Sulfur-dioxide scrubber	90.3	87 (189)	41.5 d	0.005 (0.2)	...	89
304	S30400	...	Synthetic resins processing; no aeration; no agitation. Sulfur-dioxide scrubber	2.6	52 (127)	41.5 d	0.003 (0.1) max	...	89
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
304L	S30403	...	4 bar	...	135 (275)	...	Good	...	253
304L	S30403	...	5-8 bar	...	160 (320)	...	Questionable	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
304LN	S30453	...	4 bar	...	135 (275)	...	Good	...	253
304LN	S30453	...	5-8 bar	...	160 (320)	...	Questionable	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
316	S31600	...	4 bar	...	135 (275)	...	Resistant	...	253
316	S31600	...	5-8 bar	...	160 (320)	...	Good	...	253
316	S31600	...	No aeration; no agitation. Dilute sulfurous acid, in propylene-glycol solution	...	26 (80)	30 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Sulfurous acid and caustic soda in varying concentrations, water effluent of air heater washing, pH 1.1-12.6	...	65 (150)	2.4 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.1 d	0.3 (12)	Crevice attack	89
316	S31600	Sensitized	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.1 d	0.3 (11)	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-365 (660-690)	8.3 d	0.14 (5.4)	...	89
316	S31600	Sensitized	Slight to moderate aeration; rapid agitation. Sulfurous and sulfuric acids, pH ~2.5 (clay dust washer)	...	349-395 (660-690)	8.3 d	0.15 (5.9)	...	89
316	S31600	...	Strong aeration; rapid agitation. Plus seawater, 1.7% sodium chloride	~2.05	13 (55)	30 d	0.003 (0.1)	Crevice attack	89
316	S31600	Welded	Synthetic resin processing; field or pilot plant test; no aeration; no agitation	~0.01	104 (219)	41.5 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfurous Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	Synthetic resin processing; no aeration; no agitation	~0.01	104 (219)	41.5 d	0.003 (0.1) max	...	89
316	S31600	...	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	2.6	52 (127)	41.5 d	0.003 (0.1) max	...	89
316	S31600	Welded	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	2.6	52 (127)	41.5 d	0.003 (0.1) max	...	89
316	S31600	...	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	90.3	87 (189)	41.5 d	0.003 (0.1) max	...	89
316	S31600	...	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	90.3	87 (189)	41.5 d	0.003 (0.1) max	...	89
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
316F	S31620	...	4 bar	...	135 (275)	...	Good	...	253
316F	S31620	...	5-8 bar	...	160 (320)	...	Questionable	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
316L	S31603	...	4 bar	...	135 (275)	...	Resistant	...	253
316L	S31603	...	5-8 bar	...	160 (320)	...	Good	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
316LN	S31653	...	4 bar	...	135 (275)	...	Resistant	...	253
316LN	S31653	...	5-8 bar	...	160 (320)	...	Good	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
316Ti	S31635	...	4 bar	...	135 (275)	...	Resistant	...	253
316Ti	S31635	...	5-8 bar	...	160 (320)	...	Good	...	253
317	S31700	...	Slight to moderate aeration; rapid agitation. Sulfurous acid and caustic soda in varying concentrations, water effluent of air heater washing, pH 1.1-12.6	...	65 (150)	2.4 d	0.005 (0.2)	...	89
317	S31700	...	Strong aeration; rapid agitation. Plus seawater, 1.7% sodium chloride	~2.05	13 (55)	30 d	.003 (0.1) max	...	89
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
317L	S31703	...	4 bar	...	135 (275)	...	Resistant	...	253
317L	S31703	...	5-8 bar	...	160 (320)	...	Good	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
317LN	S31725	...	4 bar	...	135 (275)	...	Resistant	...	253
317LN	S31725	...	5-8 bar	...	160 (32)	...	Good	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
321	S32100	...	4 bar	...	135 (275)	...	Good	...	253
321	S32100	...	5-8 bar	...	160 (320)	...	Questionable	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
329	S32900	...	4 bar	...	135 (275)	...	Resistant	...	253
329	S32900	...	5-8 bar	...	160 (320)	...	Good	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
347	S34700	...	4 bar	...	135 (275)	...	Good	...	253
347	S34700	...	5-8 bar	...	160 (320)	...	Questionable	...	253
403	S40300	...	...	Saturated	20 (68)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Sulfurous Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
403	S40300	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
403	S40300	...	4 bar	...	135 (275)	...	Poor	...	253
403	S40300	...	5-8 bar	...	160 (320)	...	Poor	...	253
405	S40500	...	...	Saturated	20 (68)	...	Poor	...	253
405	S40500	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
405	S40500	...	4 bar	...	135 (275)	...	Poor	...	253
405	S40500	...	5-8 bar	...	160 (320)	...	Poor	...	253
409	S40900	...	...	Saturated	20 (68)	...	Poor	...	253
409	S40900	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
409	S40900	...	4 bar	...	135 (275)	...	Poor	...	253
409	S40900	...	5-8 bar	...	160 (320)	...	Poor	...	253
410	S41000	...	...	...	Room	...	Good	...	121
410	S41000	...	...	Saturated	20 (68)	...	Poor	...	253
410	S41000	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
410	S41000	...	4 bar	...	135 (275)	...	Poor	...	253
410	S41000	...	5-8 bar	...	160 (320)	...	Poor	...	253
416	S41600	...	...	Saturated	20 (68)	...	Poor	...	253
416	S41600	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
416	S41600	...	4 bar	...	135 (275)	...	Poor	...	253
416	S41600	...	5-8 bar	...	160 (320)	...	Poor	...	253
420	S42000	...	...	Saturated	20 (68)	...	Poor	...	253
420	S42000	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
420	S42000	...	4 bar	...	135 (275)	...	Poor	...	253
420	S42000	...	5-8 bar	...	160 (320)	...	Poor	...	253
430	S43000	...	...	Saturated	20 (68)	...	Questionable	...	253
430	S43000	...	10-20 bar	...	180-200 (356-392)	...	Poor	...	253
430	S43000	...	4 bar	...	135 (275)	...	Questionable	...	253
430	S43000	...	5-8 bar	...	160 (320)	...	Poor	...	253
434	S43400	...	...	Saturated	20 (68)	...	Resistant	...	253
434	S43400	...	10-20 bar	...	180-200 (356-392)	...	Questionable	...	253
434	S43400	...	4 bar	...	135 (275)	...	Resistant	...	253
434	S43400	...	5-8 bar	...	160 (320)	...	Good	...	253
Carpenter 20	...	...	Slight to moderate aeration; rapid agitation. Sulfurous acid and caustic soda in varying concentrations, water effluent of air heater washing, pH 1.1-12.6	...	65 (150)	2.4 d	0.003 (0.1) max	...	89
Carpenter 20	...	Cast	Strong aeration; rapid agitation. Plus seawater, 1.7% sodium chloride	~2.05	13 (55)	30 d	0.003 (0.1) max	Crevice attack	89
Carpenter 20	...	Cast	Synthetic resin processing; no aeration; no agitation	~0.01	104 (219)	41.5 d	0.003 (0.1) max	...	89
Carpenter 20	...	Cast	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	2.6	52 (127)	41.5 d	0.003 (0.1) max	...	89
Carpenter 20	...	Cast	Synthetic resin processing; no aeration; no agitation. Sulfur-dioxide scrubber	90.3	87 (189)	41.5 d	0.003 (0.1)	...	89
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	10-20 bar	...	180-200 (356-392)	...	Good	...	253
F51	S31803	...	4 bar	...	135 (275)	...	Resistant	...	253
F51	S31803	...	5-8 bar	...	160 (320)	...	Good	...	253

Super Phosphate

The most important phosphorus fertilizer, derived by action of sulfuric acid on phosphate rock (mostly tribasic calcium phosphate) to produce a mix of gypsum and monobasic calcium phosphate. Typical composition: $CaH_4(PO_4)_2 \cdot H_2O$ (30%), $CaHPO_4$ (10%), $CaSO_4$ (45%), iron oxide, alumina, silica (10%), water (5%).

Corrosion Behavior of Various Metals and Alloys in Super Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Tannic Acid

Tannic acid, $C_{14}H_{10}O_9$, also known as digallic acid, tannin, and gallotannin, is a yellowish powder that decomposes at 210 °C (410 °F). Tannic acid is derived from nutgalls. It is soluble in water and alcohol, and is insoluble in acetone and ether. Tannic acid is used in tanning, textiles, and as an alcohol denaturant. An amorphous form of tannic acid, also known as pentadigalloylglucose, exists with the formula $C_{76}H_{52}O_{46}$. It is a yellowish to brownish powder that is very soluble in alcohol and ether. It also decomposes between 210 and 215 °C (410 and 419 °F). This form is used to clarify wine or beer, as a reagent, and as a mordant in dyeing.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. During laboratory tests run at ambient temperature and 100% relative humidity, aluminum alloys 3003 and 5154 were mildly attacked (0.05 mm/yr, or 2 mils/yr) by solid tannic acid. Aqueous solutions of 0.01 to 20% tannic acid produced mild attack (0.05 mm/yr, or 2 mils/yr) of aluminum alloy 1100 at ambient temperature, moderate attack (0.23 mm/yr, or 9 mils/yr) at 50 °C (122 °F), and aggressive attack at 100 °C (212 °F). The tanning industry utilizes aluminum alloy processing equipment.

Zirconium. Zirconium resists corrosion in tannic acid.

Super Phosphate

The most important phosphorus fertilizer, derived by action of sulfuric acid on phosphate rock (mostly tribasic calcium phosphate) to produce a mix of gypsum and monobasic calcium phosphate. Typical composition: $CaH_4(PO_4)_2{\cdot}H_2O$ (30%), $CaHPO_4$ (10%), $CaSO_4$ (45%), iron oxide, alumina, silica (10%), water (5%).

Corrosion Behavior of Various Metals and Alloys in Super Phosphate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253

Tannic Acid

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Zirconium. Zirconium resists corrosion in tannic acid.

Corrosion Behavior of Various Metals and Alloys in Tannic Acid

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	...	...	...	...	Resistant	...	92
Aluminum-manganese alloys	...	...	...	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Good	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	...	...	...	Good	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Good	...	93
Muntz metal	C28000	...	...	...	...	...	Good	...	93
Naval brass	C46400	...	...	...	...	...	Good	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Magnesium	...	...	...	3	Room	...	Poor	...	119
Tin	...	...	...	10	20 (68)	...	Resistant	...	94
Tin	...	...	...	10	60 (140)	...	Resistant	...	94
Tin	...	...	...	10	100 (212)	...	Poor	...	94
Refractory metals and alloys									
Titanium	...	...	...	25	100 (212)	...	Resistant	...	90
Zr702	R60702	...	...	25	35-100 (95-212)	...	0.03 (1) max	...	15
Stainless steels									
301	S30100	...	...	5	20 (68)	...	Resistant	...	253
301	S30100	...	...	5	Boiling	...	Resistant	...	253
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
301	S30100	...	...	50	20 (68)	...	Resistant	...	253
301	S30100	...	...	50	Boiling	...	Resistant	...	253
302	S30200	...	...	5	20 (68)	...	Resistant	...	253
302	S30200	...	...	5	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	50	20 (68)	...	Resistant	...	253
302	S30200	...	...	50	Boiling	...	Resistant	...	253
303	S30300	...	...	5	20 (68)	...	Resistant	...	253
303	S30300	...	...	5	20 (68)	...	Resistant	...	253
303	S30300	...	...	5	Boiling	...	Resistant	...	253
303	S30300	...	...	5	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Tannic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	20 (68)	...	Resistant	...	253
303	S30300	...	...	50	Boiling	...	Good	...	253
303	S30300	...	...	50	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Good	...	121
304	S30400	...	...	5	20 (68)	...	Resistant	...	253
304	S30400	...	...	5	Boiling	...	Resistant	...	253
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	50	20 (68)	...	Resistant	...	253
304	S30400	...	...	50	Boiling	...	Resistant	...	253
304L	S30403	...	...	5	20 (68)	...	Resistant	...	253
304L	S30403	...	...	5	Boiling	...	Resistant	...	253
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304L	S30403	...	...	50	20 (68)	...	Resistant	...	253
304L	S30403	...	...	50	Boiling	...	Resistant	...	253
304LN	S30453	...	...	5	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	5	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	50	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	50	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121
316	S31600	...	...	5	20 (68)	...	Resistant	...	253
316	S31600	...	...	5	Boiling	...	Resistant	...	253
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	50	20 (68)	...	Resistant	...	253
316	S31600	...	...	50	Boiling	...	Resistant	...	253
316F	S31620	...	...	5	20 (68)	...	Resistant	...	253
316F	S31620	...	...	5	Boiling	...	Resistant	...	253
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316F	S31620	...	...	50	20 (68)	...	Resistant	...	253
316F	S31620	...	...	50	Boiling	...	Resistant	...	253
316L	S31603	...	...	5	20 (68)	...	Resistant	...	253
316L	S31603	...	...	5	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	50	20 (68)	...	Resistant	...	253
316L	S31603	...	...	50	Boiling	...	Resistant	...	253
316LN	S31653	...	...	5	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	5	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	50	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	50	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	5	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	5	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	50	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Tannic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	50	Boiling	...	Resistant	...	253
317L	S31703	...	...	5	20 (68)	...	Resistant	...	253
317L	S31703	...	...	5	Boiling	...	Resistant	...	253
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317L	S31703	...	...	50	20 (68)	...	Resistant	...	253
317L	S31703	...	...	50	Boiling	...	Resistant	...	253
317LN	S31725	...	...	5	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	5	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	50	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	50	Boiling	...	Resistant	...	253
321	S32100	...	...	5	20 (68)	...	Resistant	...	253
321	S32100	...	...	5	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	50	20 (68)	...	Resistant	...	253
321	S32100	...	...	50	Boiling	...	Resistant	...	253
329	S32900	...	...	5	20 (68)	...	Resistant	...	253
329	S32900	...	...	5	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	50	20 (68)	...	Resistant	...	253
329	S32900	...	...	50	Boiling	...	Resistant	...	253
347	S34700	...	...	5	20 (68)	...	Resistant	...	253
347	S34700	...	...	5	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	50	20 (68)	...	Resistant	...	253
347	S34700	...	...	50	Boiling	...	Resistant	...	253
403	S40300	...	...	5	20 (68)	...	Resistant	...	253
403	S40300	...	...	5	Boiling	...	Good	...	253
403	S40300	...	...	10	20 (68)	...	Resistant	...	253
403	S40300	...	...	10	Boiling	...	Good	...	253
403	S40300	...	...	50	20 (68)	...	Resistant	...	253
403	S40300	...	...	50	Boiling	...	Good	...	253
405	S40500	...	...	5	20 (68)	...	Resistant	...	253
405	S40500	...	...	5	Boiling	...	Good	...	253
405	S40500	...	...	10	20 (68)	...	Resistant	...	253
405	S40500	...	...	10	Boiling	...	Good	...	253
405	S40500	...	...	50	20 (68)	...	Resistant	...	253
405	S40500	...	...	50	Boiling	...	Good	...	253
409	S40900	...	...	5	20 (68)	...	Resistant	...	253
409	S40900	...	...	5	Boiling	...	Good	...	253
409	S40900	...	...	10	20 (68)	...	Resistant	...	253
409	S40900	...	...	10	Boiling	...	Good	...	253
409	S40900	...	...	50	20 (68)	...	Resistant	...	253
409	S40900	...	...	50	Boiling	...	Good	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	5	20 (68)	...	Resistant	...	253
410	S41000	...	...	5	Boiling	...	Good	...	253
410	S41000	...	...	10	20 (68)	...	Resistant	...	253
410	S41000	...	...	10	Boiling	...	Good	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Tannic Acid (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	50	20 (68)	...	Resistant	...	253
410	S41000	...	...	50	Boiling	...	Good	...	253
416	S41600	...	...	5	20 (68)	...	Resistant	...	253
416	S41600	...	...	5	Boiling	...	Good	...	253
416	S41600	...	...	10	20 (68)	...	Resistant	...	253
416	S41600	...	...	10	Boiling	...	Good	...	253
416	S41600	...	...	50	20 (68)	...	Resistant	...	253
416	S41600	...	...	50	Boiling	...	Good	...	253
420	S42000	...	...	5	20 (68)	...	Resistant	...	253
420	S42000	...	...	5	Boiling	...	Good	...	253
420	S42000	...	...	10	20 (68)	...	Resistant	...	253
420	S42000	...	...	10	Boiling	...	Good	...	253
420	S42000	...	...	50	20 (68)	...	Resistant	...	253
420	S42000	...	...	50	Boiling	...	Good	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	5	20 (68)	...	Resistant	...	253
430	S43000	...	...	5	Boiling	...	Resistant	...	253
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Resistant	...	253
430	S43000	...	...	50	20 (68)	...	Resistant	...	253
430	S43000	...	...	50	Boiling	...	Good	...	253
434	S43400	...	...	5	20 (68)	...	Resistant	...	253
434	S43400	...	...	5	Boiling	...	Resistant	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
434	S43400	...	...	50	20 (68)	...	Resistant	...	253
434	S43400	...	...	50	Boiling	...	Good	...	253
F51	S31803	...	...	5	20 (68)	...	Resistant	...	253
F51	S31803	...	...	5	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	50	20 (68)	...	Resistant	...	253
F51	S31803	...	...	50	Boiling	...	Resistant	...	253

Tar

A dark, viscous, usually pungent substance, tar is derived from the destructive distillation of various organic compounds such as wood, coal, or shale, that is used forr various industrial purposes.

Corrosion Behavior of Various Metals and Alloys in Tar

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Pure	...	20 (68)	...	Resistant	...	253
301	S30100	...	Pure	...	Hot	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Tar (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	Pure	...	20 (68)	...	Resistant	...	253
302	S30200	...	Pure	...	Hot	...	Resistant	...	253
303	S30300	...	Pure	...	20 (68)	...	Resistant	...	253
303	S30300	...	Pure	...	Hot	...	Resistant	...	253
303	S30300	...	Pure	...	20 (68)	...	Resistant	...	253
303	S30300	...	Pure	...	Hot	...	Resistant	...	253
304	S30400	...	Pure	...	20 (68)	...	Resistant	...	253
304	S30400	...	Pure	...	Hot	...	Resistant	...	253
304L	S30403	...	Pure	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Pure	...	Hot	...	Resistant	...	253
304LN	S30453	...	Pure	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Pure	...	Hot	...	Resistant	...	253
316	S31600	...	Pure	...	20 (68)	...	Resistant	...	253
316	S31600	...	Pure	...	Hot	...	Resistant	...	253
316F	S31620	...	Pure	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Pure	...	Hot	...	Resistant	...	253
316L	S31603	...	Pure	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Pure	...	Hot	...	Resistant	...	253
316LN	S31653	...	Pure	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Pure	...	Hot	...	Resistant	...	253
316Ti	S31635	...	Pure	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Pure	...	Hot	...	Resistant	...	253
317L	S31703	...	Pure	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Pure	...	Hot	...	Resistant	...	253
317LN	S31725	...	Pure	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Pure	...	Hot	...	Resistant	...	253
321	S32100	...	Pure	...	20 (68)	...	Resistant	...	253
321	S32100	...	Pure	...	Hot	...	Resistant	...	253
329	S32900	...	Pure	...	20 (68)	...	Resistant	...	253
329	S32900	...	Pure	...	Hot	...	Resistant	...	253
347	S34700	...	Pure	...	20 (68)	...	Resistant	...	253
347	S34700	...	Pure	...	Hot	...	Resistant	...	253
403	S40300	...	Pure	...	20 (68)	...	Resistant	...	253
403	S40300	...	Pure	...	Hot	...	Resistant	...	253
405	S40500	...	Pure	...	20 (68)	...	Resistant	...	253
405	S40500	...	Pure	...	Hot	...	Resistant	...	253
409	S40900	...	Pure	...	20 (68)	...	Resistant	...	253
409	S40900	...	Pure	...	Hot	...	Resistant	...	253
410	S41000	...	Pure	...	20 (68)	...	Resistant	...	253
410	S41000	...	Pure	...	Hot	...	Resistant	...	253
416	S41600	...	Pure	...	20 (68)	...	Resistant	...	253
416	S41600	...	Pure	...	Hot	...	Resistant	...	253
420	S42000	...	Pure	...	20 (68)	...	Resistant	...	253
420	S42000	...	Pure	...	Hot	...	Resistant	...	253
430	S43000	...	Pure	...	20 (68)	...	Resistant	...	253
430	S43000	...	Pure	...	Hot	...	Resistant	...	253
434	S43400	...	Pure	...	20 (68)	...	Resistant	...	253
434	S43400	...	Pure	...	Hot	...	Resistant	...	253
F51	S31803	...	Pure	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Pure	...	Hot	...	Resistant	...	253

Tartaric Acid

Tartaric acid, $HOOC(CHOH)_2COOH$, is a water- and alcohol-soluble colorless crystalline solid with an acid taste and a melting temperature of 170 °C (338 °F). It is also known as dihydroxysuccinic acid. Tartaric acid is used as a chemical intermediate and a sequestrant, as well as in tanning, effervescent beverages, baking powder, ceramics, photography, textile processing, mirror silvering, and metal coloring.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Type 304 stainless steel has been used in tartaric acid (and in citric acid) at moderate temperatures. Type 316 stainless steel has been suggested for all concentrations up to the boiling point of tartaric acid.

Copper. Copper and its alloys corrode rather slowly when exposed to various concentrations of tartaric acid.

Aluminum. Aluminum alloys 3003 and 5154 were resistant to solid tartaric acid in laboratory tests conducted under conditions of 100% relative humidity at ambient temperature. In other laboratory tests, 1100 alloy was resistant to aqueous solutions (0.1 to 55%) at ambient temperature, but these solutions were corrosive at 50 °C (122 °F) and very corrosive at 100 °C (212 °F). Tartaric acid has been processed in aluminum alloy filters and crystallizers and has been stored in aluminum alloy tanks.

Corrosion Behavior of Various Metals and Alloys in Tartaric Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Solution	...	...	...	Resistant	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Resistant	...	93
75-25 cupronickel	C71300	...	...	2	25 (75)	...	0.04 (1.6)	...	63
80-20 cupronickel	C71000	...	...	5	25 (75)	...	0.03 (1) max	...	63
90-10 cupronickel	C70600	...	...	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	...	...	...	...	Resistant	...	93
Aluminum bronze	...	...	...	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	...	...	...	...	Questionable	...	93
Brass	...	...	...	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	...	10	25 (75)	...	0.05 (2) max	...	63
Cartridge brass	C26000	...	...	30	25 (75)	...	1.3 (50) max	...	63
Cartridge brass	C26000	...	...	50	25 (75)	...	1.3 (50) max	...	63
Cartridge brass	C26000	...	...	100	25 (75)	...	0.05 (2) max	...	63
Cartridge brass	C26000	...	...	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	...	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	...	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	...	...	...	...	Resistant	...	93
Muntz metal	C28000	...	...	...	...	...	Questionable	...	93
Naval brass	C46400	...	...	...	...	...	Questionable	...	93
Nickel-silver	...	...	...	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	...	...	...	...	Resistant	...	93
Red brass	C23000	...	...	10	25 (75)	...	0.05 (2) max	...	63
Red brass	C23000	...	...	30	25 (75)	...	1.3 (50) max	...	63
Red brass	C23000	...	...	50	25 (75)	...	1.3 (50) max	...	63

(Continued)

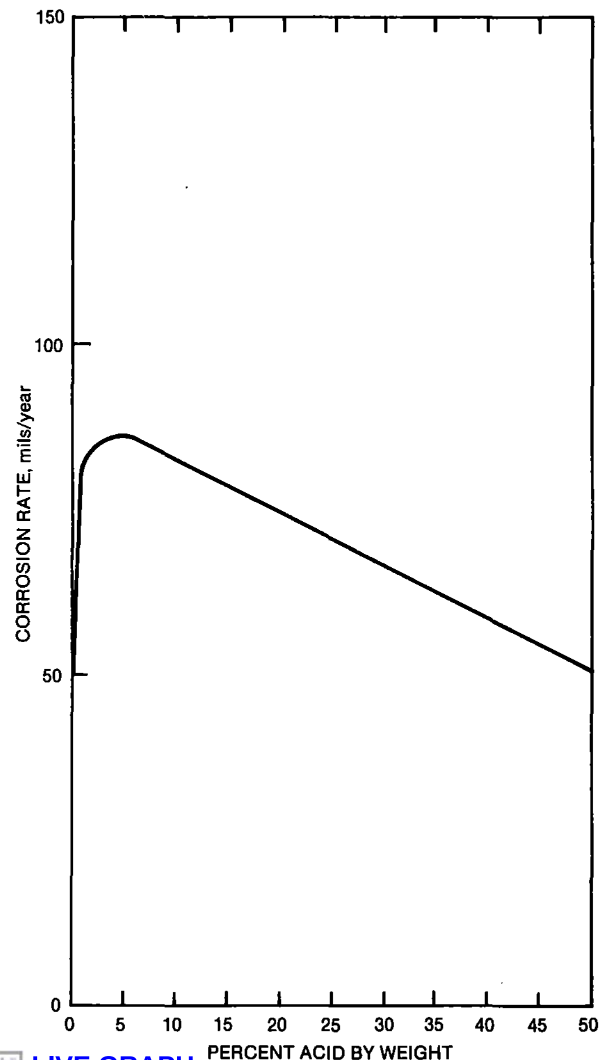
Corrosion Behavior of Various Metals and Alloys in Tartaric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Red brass	C23000	...	...	100	25 (75)	...	0.05 (2) max	...	63
Red brass	C23000	...	...	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Resistant	...	93
Miscellaneous									
Gold	P00016	...	...	All	Boiling	...	0.05 (2) max	...	8
Magnesium	...	...	...	All	Room	...	Poor	...	119
Silver	P07010	...	...	All	100 (212)	...	0.05 (2) max	...	4
Silver	P07010	...	Oxygen increases attack in dilute tartaric acid at room temperature	All	100 (212)	...	0.05 (2) max	...	4
Tin	...	...	...	...	60 (140)	...	Resistant	...	94
Tin	...	...	...	...	100 (212)	...	Poor	...	94
Tin	...	...	Nonaerated solutions	...	20 (68)	...	Resistant	...	94
Nickel and alloys									
Incoloy 800	N08800	Cold-rolled, annealed sheet.	Solutions were prepared with reagent-grade chemicals	10	80 (176)	7 d	0.003 (0.1) max	...	44
Inconel 690	N06690	...	...	10	25 (77)	...	0.03 (1) max	...	57
Nickel 200	N02200	...	In vacuum evaporating pan	57	54 (130)	...	0.19 (7.5)	...	44
Refractory metals and alloys									
Niobium	R04210	...	...	20	Room	...	Resistant	...	2
Niobium	R04210	...	...	20	Boiling	...	Resistant	...	2
Titanium	...	...	...	10-50	100 (212)	...	0.13 (5) max	...	90
Titanium	...	...	...	10	60 (140)	...	0.003 (0.1)	...	90
Titanium	...	...	...	25	60 (140)	...	0.003 (0.1)	...	90
Titanium	...	...	...	50	60 (140)	...	0.003 (0.1) max	...	90
Titanium	...	...	...	10	100 (212)	...	0.003 (0.1)	...	90
Titanium	...	...	...	25	100 (212)	...	Resistant	...	90
Titanium	...	...	...	50	100 (212)	...	0.01 (0.5)	...	90
Zr702	R60702	...	...	10-50	35-100 (95-212)	...	0.03 (1) max	...	15
Stainless steels									
301	S30100	...	...	10	20 (68)	...	Resistant	...	253
301	S30100	...	...	10	Boiling	...	Resistant	...	253
302	S30200	...	...	10	20 (68)	...	Resistant	...	253
302	S30200	...	...	10	Boiling	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	20 (68)	...	Resistant	...	253
303	S30300	...	...	10	Boiling	...	Questionable	...	253
303	S30300	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	...	10	21 (70)	...	Resistant	...	121
304	S30400	...	...	10	20 (68)	...	Resistant	...	253
304	S30400	...	...	10	Boiling	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Commercial grade	...	202 (395)	5 d	0.05 (2)	...	89
304	S30400	...	No aeration; rapid agitation. Vapors over tartaric acid, decomposition products, acetic and formic acids, etc.	...	202 (395)	5 d	0.08 (3)	...	89
304L	S30403	...	...	10	20 (68)	...	Resistant	...	253
304L	S30403	...	...	10	Boiling	...	Resistant	...	253
304LN	S30453	...	...	10	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	...	10	21 (70)	...	Good	...	121

(Continued)

Corrosion Behavior of Various Metals and Alloys in Tartaric Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	10	20 (68)	...	Resistant	...	253
316	S31600	...	...	10	Boiling	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Commercial grade	...	202 (395)	5 d	0.1 (4.5)	...	89
316	S31600	...	No aeration; rapid agitation. Vapors over tartaric acid, decomposition products, acetic and formic acids, etc.	...	202 (395)	5 d	0.02 (0.6)	...	89
316F	S31620	...	...	10	20 (68)	...	Resistant	...	253
316F	S31620	...	...	10	Boiling	...	Resistant	...	253
316L	S31603	...	...	10	20 (68)	...	Resistant	...	253
316L	S31603	...	...	10	Boiling	...	Resistant	...	253
316LN	S31653	...	...	10	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	10	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	10	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	10	Boiling	...	Resistant	...	253
317	S31700	...	No aeration; rapid agitation. Commercial grade	...	202 (395)	5 d	0.2 (6.3)	...	89
317	S31700	...	No aeration; rapid agitation. Vapors over tartaric acid, decomposition products, acetic and formic acids, etc.	...	202 (395)	5 d	0.03 (1)	...	89
317L	S31703	...	...	10	20 (68)	...	Resistant	...	253
317L	S31703	...	...	10	Boiling	...	Resistant	...	253
317LN	S31725	...	...	10	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	10	Boiling	...	Resistant	...	253
321	S32100	...	...	10	20 (68)	...	Resistant	...	253
321	S32100	...	...	10	Boiling	...	Resistant	...	253
329	S32900	...	...	10	20 (68)	...	Resistant	...	253
329	S32900	...	...	10	Boiling	...	Resistant	...	253
347	S34700	...	...	10	20 (68)	...	Resistant	...	253
347	S34700	...	...	10	Boiling	...	Resistant	...	253
403	S40300	...	...	10	20 (68)	...	Good	...	253
403	S40300	...	...	10	Boiling	...	Questionable	...	253
405	S40500	...	...	10	20 (68)	...	Good	...	253
405	S40500	...	...	10	Boiling	...	Questionable	...	253
409	S40900	...	...	10	20 (68)	...	Good	...	253
409	S40900	...	...	10	Boiling	...	Questionable	...	253
410	S41000	...	...	10	21 (70)	...	Good	...	121
410	S41000	...	...	10	20 (68)	...	Good	...	253
410	S41000	...	...	10	Boiling	...	Questionable	...	253
416	S41600	...	...	10	20 (68)	...	Good	...	253
416	S41600	...	...	10	Boiling	...	Questionable	...	253
420	S42000	...	...	10	20 (68)	...	Good	...	253
420	S42000	...	...	10	Boiling	...	Questionable	...	253
430	S43000	...	...	10	21 (70)	...	Good	...	121
430	S43000	...	...	10	20 (68)	...	Resistant	...	253
430	S43000	...	...	10	Boiling	...	Questionable	...	253
434	S43400	...	...	10	20 (68)	...	Resistant	...	253
434	S43400	...	...	10	Boiling	...	Resistant	...	253
F51	S31803	...	...	10	20 (68)	...	Resistant	...	253
F51	S31803	...	...	10	Boiling	...	Resistant	...	253



LIVE GRAPH
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Aluminum. Effect of tartaric acid on alloy 1100 at 100 °C (212 °F). Source: *Guidelines for the Use of Aluminum with Food and Chemicals: Compatibility Data on Aluminum in the Food and Chemical Process Industries*, 5th ed., The Aluminum Association, Washington, DC, 1984, 25.

Thioglycolic Acid

Also known as mercaptoacetic acid, $HSCH_2COOH$ is a liquid with a strong unpleasant odor. Used as a reagent for metals such as iron, molybdenum, silver, and tin, and in bacteriology.

Corrosion Behavior of Various Metals and Alloys in Thioglycolic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
316	S31600	...	...	...	20 (68)	...	Good	...	253
316	S31600	...	...	...	Boiling	...	Good	...	253
316L	S31603	...	...	...	20 (68)	...	Good	...	253
316L	S31603	...	...	...	Boiling	...	Good	...	253
316LN	S31653	...	...	...	20 (68)	...	Good	...	253
316LN	S31653	...	...	...	Boiling	...	Good	...	253
316Ti	S31635	...	...	...	20 (68)	...	Good	...	253
316Ti	S31635	...	...	...	Boiling	...	Good	...	253
317L	S31703	...	...	...	20 (68)	...	Good	...	253
317L	S31703	...	...	...	Boiling	...	Good	...	253
317LN	S31725	...	...	...	20 (68)	...	Good	...	253
317LN	S31725	...	...	...	Boiling	...	Good	...	253
329	S32900	...	...	...	20 (68)	...	Good	...	253
329	S32900	...	...	...	Boiling	...	Good	...	253
F51	S31803	...	...	...	20 (68)	...	Good	...	253
F51	S31803	...	...	...	Boiling	...	Good	...	253

Toluene

Also known as methylbenezne or phenylmethane, $C_6H_5CH_3$ is a flammable, toxic, colorless liquid. Insoluble in water and soluble in alcohol and ether it is used in explosives, high-octane gasoline, and organic synthesis.

Corrosion Behavior of Various Metals and Alloys in Toluene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Toluene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Trichloroethylene

Trichloroethylene, $CHCl:CCl_2$, is a heavy, stable toxic liquid with a chloroform aroma. It is slightly soluble in water, is soluble in greases and common organic solvents, and boils at 87 °C (190 °F). Trichloroethylene is used in metal degreasing, solvent extraction, and dry cleaning, and as a fumigant and chemical intermediate.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. In limited laboratory tests, 3003 alloy was resistant to trichloroethylene in the dry condition at ambient temperature, at 50 °C (122 °F), and under refluxing conditions. The presence of water accelerates the corrosive effects of trichloroethylene. Inhibited trichloroethylene has been used for degreasing of aluminum alloy products. *Caution:* Under certain conditions, some hydrocarbons may produce a rapid rate of corrosion of aluminum or a violent reaction. Consequently, the service conditions to ensure safety should be recognized or established before aluminum alloys are used with halogenated hydrocarbons.

Zirconium. Zirconium resists corrosion in trichloroethylene.

Corrosion Behavior of Various Metals and Alloys in Trichlorethylene

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (99.0-99.5%)	A91199	...	Liquid	...	20 (68)	...	Questionable	...	92
Aluminum alloys	...	...	Liquid	...	20 (68)	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	Moist	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Dry	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Moist	...	...	...	Good	...	93
Admiralty brass	C44300	...	Dry	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Moist	...	...	...	Good	...	93
Aluminum bronze	...	...	Dry	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Moist	...	...	...	Good	...	93
Ampco 8, aluminum bronze	C61300	...	...	...	...	...	0.5 (20) max	...	96
Architectural bronze	C38500	...	Dry	...	...	...	Resistant	...	93
Architectural bronze	C38500	...	Moist	...	...	...	Questionable	...	93
Brass	...	...	Dry	...	...	...	Resistant	...	93
Brass	...	...	Moist	...	...	...	Good	...	93
Cartridge brass	C26000	...	Dry	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Moist	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	Dry	...	...	...	Resistant	...	93
Commercial bronze	C22000	...	Moist	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Dry	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Moist	...	...	...	Good	...	93
Free-cutting brass	C36000	...	Dry	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Moist	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Dry	...	...	...	Resistant	...	93
Muntz metal	C28000	...	Moist	...	...	...	Questionable	...	93
Naval brass	C46400	...	Dry	...	...	...	Resistant	...	93
Naval brass	C46400	...	Moist	...	...	...	Questionable	...	93
Nickel-silver	...	...	Dry	18	...	...	Resistant	...	93
Nickel-silver	...	...	Moist	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Moist	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Dry	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Moist	...	...	...	Good	...	93
Phosphor copper	C12200	...	Dry	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Moist	...	...	...	Good	...	93
Red brass	C23000	...	Dry	...	...	...	Resistant	...	93
Red brass	C23000	...	Moist	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Moist	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Dry	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Moist	...	...	...	Good	...	93
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Refractory metals and alloys									
Niobium	R04210	...	...	99	Boiling	...	Resistant	...	2
Titanium	...	...	...	99	Boiling	...	0.13 (5) max	...	20
Titanium	...	...	...	99	Boiling	...	0.13 (5.1) max	...	90
Titanium	...	...	Plus 50% H_2O	50	25 (77)	...	0.003 (0.1) max	...	90
Zr702	R60702	...	BP 87°C (189°F)	99	Boiling	...	0.13 (5) max	...	15
Stainless steels									
301	S30100	...	...	Anhydrous	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Trichlorethylene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
302	S30200	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
303	S30300	...	...	Anhydrous	Boiling	...	Resistant	...	253
304	S30400	...	...	Anhydrous	Boiling	...	Resistant	...	253
304L	S30403	...	...	Anhydrous	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Anhydrous	Boiling	...	Resistant	...	253
316	S31600	...	...	Anhydrous	Boiling	...	Resistant	...	253
316F	S31620	...	...	Anhydrous	Boiling	...	Resistant	...	253
316L	S31603	...	...	Anhydrous	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Anhydrous	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Anhydrous	Boiling	...	Resistant	...	253
317L	S31703	...	...	Anhydrous	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Anhydrous	Boiling	...	Resistant	...	253
321	S32100	...	...	Anhydrous	Boiling	...	Resistant	...	253
329	S32900	...	...	Anhydrous	Boiling	...	Resistant	...	253
347	S34700	...	...	Anhydrous	Boiling	...	Resistant	...	253
403	S40300	...	...	Anhydrous	Boiling	...	Resistant	...	253
405	S40500	...	...	Anhydrous	Boiling	...	Resistant	...	253
409	S40900	...	...	Anhydrous	Boiling	...	Resistant	...	253
410	S41000	...	...	100	Room	...	Poor	...	121
410	S41000	...	...	Anhydrous	Boiling	...	Resistant	...	253
416	S41600	...	...	Anhydrous	Boiling	...	Resistant	...	253
420	S42000	...	...	Anhydrous	Boiling	...	Resistant	...	253
430	S43000	...	...	Anhydrous	Boiling	...	Resistant	...	253
434	S43400	...	...	Anhydrous	Boiling	...	Resistant	...	253
F51	S31803	...	...	Anhydrous	Boiling	...	Resistant	...	253

Trichloroacetic Acid

Trichloroacetic acid, CCl_3COOH, is a colorless deliquescent crystalline solid that has a melting point of 57.5 °C (134 °F) and a boiling point of 198 °C (388 °F). Soluble in water, alcohol, and ether, it is toxic with a strong pungent odor. Trichloroacetic acid is used as a laboratory reagent, a herbicide, in medicine, and in microscopy.

Corrosion Behavior of Various Metals and Alloys in Trichloroacetic Acid

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	...	...	...	...	Questionable	...	92
Copper and alloys									
70-30 cupronickel	C71500	...	...	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	...	...	...	...	Good	...	93
Admiralty brass	C44300	...	...	...	...	...	Questionable	...	93
Aluminum bronze	...	...	...	...	...	...	Good	...	93
Architectural bronze	C38500	...	...	...	...	...	Poor	...	93
Brass	...	...	...	...	...	...	Questionable	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Trichloroacetic Acid (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Cartridge brass	C26000	...	...	...	...	...	Poor	...	93
Commercial bronze	C22000	...	...	...	...	...	Good	...	93
Electrolytic copper	C11000	...	...	...	...	...	Good	...	93
Free-cutting brass	C36000	...	...	...	...	...	Poor	...	93
Muntz metal	C28000	...	...	...	...	...	Poor	...	93
Naval brass	C46400	...	...	...	...	...	Poor	...	93
Nickel-silver	...	...	...	18	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	...	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	...	...	...	...	Good	...	93
Phosphor copper	C12200	...	...	...	...	...	Good	...	93
Red brass	C23000	...	...	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	...	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	...	...	...	...	Good	...	93
Refractory metals and alloys									
Titanium	...	...	...	100	Boiling	...	15 (584)	...	90
Zr702	R60702	...	...	10-40	Room	...	0.05 (2) max	...	15
Zr702	R60702	...	...	100	Boiling	...	1.3 (50) min	...	15
Zr702	R60702	...	BP 195°C (383°F)	100	100 (212)	...	1.3 (50) min	...	15
Stainless steels									
301	S30100	...	...	80	20 (68)	...	Questionable	Pitting	253
302	S30200	...	...	80	20 (68)	...	Questionable	Pitting	253
303	S30300	...	...	80	20 (68)	...	Questionable	Pitting	253
304	S30400	...	...	80	20 (68)	...	Questionable	Pitting	253
304L	S30403	...	...	80	20 (68)	...	Questionable	Pitting	253
304LN	S30453	...	...	80	20 (68)	...	Questionable	Pitting	253
316	S31600	...	...	80	20 (68)	...	Good	Pitting	253
316F	S31620	...	...	80	20 (68)	...	Questionable	Pitting	253
316L	S31603	...	...	80	20 (68)	...	Good	Pitting	253
316LN	S31653	...	...	80	20 (68)	...	Good	Pitting	253
316Ti	S31635	...	...	80	20 (68)	...	Good	Pitting	253
317L	S31703	...	...	80	20 (68)	...	Good	Pitting	253
317LN	S31725	...	...	80	20 (68)	...	Good	Pitting	253
321	S32100	...	...	80	20 (68)	...	Questionable	Pitting	253
329	S32900	...	...	80	20 (68)	...	Good	Pitting	253
347	S34700	...	...	80	20 (68)	...	Questionable	Pitting	253
F51	S31803	...	...	80	20 (68)	...	Good	Pitting	253

Turpentine

A naturally occurring organic compound, turpentine is secreted from pine trees and is soluble in alcohol and ether but not water. Oil of turpentine is often called spirits of turpentine, or in the paint trade, turpentine. In medicine the word turpentine is reserved for the oleoresin which upon distillation yields oil of turpentine and rosin. Oil of turpentine is used principally as a solvent for paints and varnishes, because it mixes readily with the various substances used and also because it evaporates quickly, causing the paint or varnish to dry. It is also used in making such things as sealing wax and shoe polish. Very pure grades of turpentine, the oleoresin, are used medicinally.

Corrosion Behavior of Various Metals and Alloys in Turpentine

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Hot	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Hot	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Hot	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Hot	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Hot	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Hot	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Hot	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Hot	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Hot	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Hot	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Hot	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Hot	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Hot	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Hot	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Hot	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Hot	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Hot	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Hot	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Hot	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Turpentine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	...	Hot	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Hot	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Hot	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Hot	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Hot	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Hot	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Hot	...	Resistant	...	253

Urea

Urea, $CO(HN_2)_2$, also known as carbamide, is a white crystalline powder that has a melting point of 132.7 °C (270 °F). It is a natural product of animal protein metabolism and is the chief nitrogen constituent of urine. Commercially, urea is produced by the reaction of ammonia and carbon dioxide. It is soluble in water, alcohol, and benzene. Although urea is best known for its use in the preparation of fertilizers and plastics, it is used in medicine, adhesives, explosives, and as a flameproofing agent.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Type 304 and 316 stainless steels have been recommended as good choices for service in urea.

Aluminum. Tested at ambient temperature and 100% relative humidity, aluminum alloy 3003 resisted attack by solid urea, whereas alloy 5154 was mildly attacked. Aluminum alloy 3003 also resisted attack by urea in solution during other tests at ambient temperature. Urea has been distilled, dried, shipped, and stored in aluminum alloy equipment.

Zirconium. Zirconium resists corrosion in urea.

Corrosion Behavior of Various Metals and Alloys in Urea

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Magnesium	...	...	Cold aqueous solution	All	...	...	Resistant	...	119
Magnesium	...	...	Warm aqueous solution	All	...	...	Poor	...	119
Nickel and alloys									
Alloy 825	N08825	...	No aeration; slight to moderate agitation. Plus 32% ammonia, 7% carbon dioxide, water remainder, heat-exchanger head	43	32-121 (90-250)	100 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Slight to moderate aeration. Plus 32.2% ammonia, 20.5% water, 19% carbon dioxide, 0.3% inerts	28	179-182 (355-360)	150 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Turpentine (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
409	S40900	...	...	...	Hot	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Hot	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Hot	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Hot	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Hot	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Hot	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Hot	...	Resistant	...	253

Urea

Urea, $CO(HN_2)_2$, also known as carbamide, is a white crystalline powder that has a melting point of 132.7 °C (270 °F). It is a natural product of animal protein metabolism and is the chief nitrogen constituent of urine. Commercially, urea is produced by the reaction of ammonia and carbon dioxide. It is soluble in water, alcohol, and benzene. Although urea is best known for its use in the preparation of fertilizers and plastics, it is used in medicine, adhesives, explosives, and as a flameproofing agent.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Stainless Steels. Type 304 and 316 stainless steels have been recommended as good choices for service in urea.

Aluminum. Tested at ambient temperature and 100% relative humidity, aluminum alloy 3003 resisted attack by solid urea, whereas alloy 5154 was mildly attacked. Aluminum alloy 3003 also resisted attack by urea in solution during other tests at ambient temperature. Urea has been distilled, dried, shipped, and stored in aluminum alloy equipment.

Zirconium. Zirconium resists corrosion in urea.

Corrosion Behavior of Various Metals and Alloys in Urea

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Miscellaneous									
Magnesium	...	...	...	100	Room	...	Resistant	...	119
Magnesium	...	...	Cold aqueous solution	All	...	...	Resistant	...	119
Magnesium	...	...	Warm aqueous solution	All	...	...	Poor	...	119
Nickel and alloys									
Alloy 825	N08825	...	No aeration; slight to moderate agitation. Plus 32% ammonia, 7% carbon dioxide, water remainder, heat-exchanger head	43	32-121 (90-250)	100 d	0.003 (0.1) max	...	89
Alloy 825	N08825	...	Slight to moderate aeration. Plus 32.2% ammonia, 20.5% water, 19% carbon dioxide, 0.3% inerts	28	179-182 (355-360)	150 d	0.003 (0.1) max	...	89

(Continued)

Corrosion Behavior of Various Metals and Alloys in Urea (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Alloy 825	N08825	...	Slight to moderate aeration; rapid agitation. Plus 31% ammonia, 17% water, 8% carbon dioxide	44	32 (90)	42 d	0.003 (0.1) max	...	89
Refractory metals and alloys									
Ti-3Al-2.5V, grade 9	...	...	...	50	150 (302)	...	0.005 (0.2)	...	91
Titanium	...	...	...	50	150 (302)	...	Resistant	...	91
Titanium	...	...	Plus 32% NH_3+ 20.5% H_2O, 19% CO_2	28	182 (360)	...	0.08 (3.2)	...	90
Titanium D-4	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 0.65, NH_3/H_2O ratio = 4.15, 0.035-0.04% oxygen (% in CO_2)	...	180-200 (350-390)	...	.038	...	252
Titanium D-4	...	...	Urea reactor; NH3/CO2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.051	...	252
Titanium D-4	...	...	Urea reactor; NH_3/CO_2 molar ratio = 3.5, 1% oxygen (% in CO_2)	...	180-200 (350-390)	...	.069	...	252
Titanium D-5	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.087	...	252
Zr702	R60702	...	17% NH_3, 15% CO_2, 10% H_2O	58	193 (380)	...	0.03 (1) max	...	15
Stainless steels									
21Cr-6.7Ni-2.4Mo-1.4Cu	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 0.65, NH_3/H_2O ratio = 4.15, 0.035-0.04% oxygen (% in CO_2)	...	180-200 (350-390)	...	.096	...	252
21Cr-6.7Ni-2.4Mo-1.4Cu	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.151	...	252
21Cr-6.7Ni-2.4Mo-1.4Cu	...	...	Urea reactor; NH_3/CO_2 molar ratio = 3.5, 1% oxygen (% in CO_2)	...	180-200 (350-390)	...	.126	...	252
25Cr-22Ni-2Mo	...	...	Urea reactor; NH_3/CO_2 molar ratio = 3.5, 1% oxygen (% in CO_2)	...	180-200 (350-390)	...	.014	...	252
26-1	S44627	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 0.65, NH_3/H_2O ratio = 4.15, 0.035-0.04% oxygen (% in CO_2)	...	180-200 (350-390)	...	.046	...	252
26-1	S44627	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.064	...	252
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	No aeration; rapid agitation. Plus ammonia, carbon dioxide, oil, urea stripper reboiler	...	121-154 (250-310)	56 d	0.7 (28)	...	89
304	S30400	...	No aeration; slight to moderate agitation. Plus 32% ammonia, 7% carbon dioxide, water remainder, heat-exchanger head	43	32-121 (90-250)	100 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration. Plus 32.2% ammonia, 20.5% water, 19% carbon dioxide, 0.3% inerts	28	179-182 (355-360)	150 d	0.003 (0.1) max	...	89
304	S30400	...	Slight to moderate aeration; rapid agitation. Plus 31% ammonia, 17% water, 8% carbon dioxide	44	32 (90)	42 d	0.003 (0.1)	...	89
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Urea (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	No aeration; rapid agitation. Plus ammonia, carbon dioxide, oil, urea stripper reboiler	...	121-154 (250-310)	56 d	0.7 (27)	...	89
316	S31600	...	No aeration; slight to moderate agitation. Plus 32% ammonia, 7% carbon dioxide, water remainder, heat-exchanger head	43	32-121 (90-250)	100 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration. Plus 32.2% ammonia, 20.5% water, 19% carbon dioxide, 0.3% inerts	28	179-182 (355-360)	150 d	0.003 (0.1) max	...	89
316	S31600	...	Slight to moderate aeration; rapid agitation. Plus 31% ammonia, 17% water, 8% carbon dioxide	44	32 (90)	42 d	0.005 (0.2)	...	89
316 urea grade	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 0.65, NH_3/H_2O ratio = 4.15, 0.035-0.04% oxygen (% in CO_2)	...	180-200 (350-390)	...	.095	...	252
316 urea grade	...	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.174	...	252
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Urea reactor; NH_3/CO_2 molar ratio = 2.7, H_2O/CO_2 ratio = 1.0, NH_3/H_2O ratio = 2.7, 0.12-0.14% oxygen (% in CO_2)	...	180-200 (350-390)	...	.128	...	252
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
AL 904L	N08904	Crevice corrosion	Plus 17.5% CO_2, 33% NH_3, 19.5% H_2O. Oxygen added for passivation during test	30	185 (365)	62.5 d	0.12 (4.8)	...	80
Alloy 20	...	...	Urea reactor; NH_3/CO_2 molar ratio = 3.5, 1% oxygen (% in CO_2)	...	180-200 (350-390)	...	.028	...	252
Carpenter 20	...	...	Slight to moderate aeration. Plus 32.2% ammonia, 20.5% water, 19% carbon dioxide, 0.3% inerts	28	179-182 (355-360)	150 d	0.003 (0.1) max	...	89
E-Brite	S44627	...	Plus 17.5% CO_2, 33% NH_3, 19.5% H_2O. Oxygen added for passivation during test	30	185 (365)	62.5 d	0.06 (2.3)	...	80

Vegetable Oil

This is an oil extracted from the seeds, fruit, or nuts of plants and generally is considered to be a mixture of mixed glycerides. e.g., cottonseed, linseed, corn, coconut, babassu, olive, tung, peanut, perilla, oiticica, etc. Many types are edible. As plant-derived products, vegetable oils are a form of biomass. Some are reported to be convertible to liquid fuels by passing them over zeolite catalysts. They are used in shortenings, salad dressing, margarine, soaps, rubber softeners, dietary supplements, pesticide carriers and as drying oils in paints.

Corrosion Behavior of Various Metals and Alloys in Vegetable Oil

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Vegetable Oil (Continued)

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Viscose

Viscose is a solution prepared by treating cellulose with sodium hydroxide and carbon disulfide. It is used in the manufacturing of rayon and films of regenerated cellulose.

Corrosion Behavior of Various Metals and Alloys in Viscose

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
302	S30200	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
303	S30300	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
303	S30300	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
304	S30400	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
304L	S30403	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
304LN	S30453	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
316	S31600	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
316F	S31620	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
316L	S31603	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
316LN	S31653	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
316Ti	S31635	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
317L	S31703	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Viscose (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
321	S32100	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
329	S32900	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
347	S34700	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
403	S40300	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
405	S40500	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
409	S40900	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
410	S41000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
416	S41600	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
420	S42000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
430	S43000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
434	S43400	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
F51	S31803	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253

Water

Water, H_2O, is a clear, odorless, tasteless liquid that is essential for most animal and plant life and is an excellent solvent for many substances. Water has a melting point of 0 °C (32 °F) and a boiling point of 100 °C (212 °F). This chemical compound may also be termed hydrogen oxide.

Naturally occurring waters are seldom pure. Even rainwater, which is distilled by nature, contains nitrogen, oxygen, carbon dioxide, and other gases, as well as entrained dust and smoke particles. Water that runs over the ground carries with it eroded soil, decaying vegetation, living microorganisms, dissolved salts, and colloidal and suspended matter. Water that seeps through soil contains dissolved carbon dioxide and becomes acidic. Groundwater also contains salts of calcium, magnesium, iron, and manganese.

All of these foreign substances in natural water affect the structure and composition of the resulting films and corrosion products on the surface of metals, which in turn control the corrosion of the metal involved. In addition to these substances, such factors as pH, time of exposure, temperature, motion, and fluid agitation influence the aqueous corrosion of the metal.

Cooling Water. The quality of water used in shell and tube heat exchangers can vary from season to season and year to year, particularly if the water is taken from a river that discharges into a bay or sea. In one case, for example, a plant had 64 identical AISI type 304 stainless steel condensers that were cooled on the shell side with river water that varied in chloride content from less than 50 ppm to as high as 2000 ppm. The stainless steel tubes failed by external pitting at the baffles. It was discovered that an almost perfect correlation could be obtained by plotting the average monthly chloride content against the number of leaking condensers retubed that month.

In a similar case, a series of stainless steel heat exchangers cooled with recirculating treated water had been in service for more than 10 years. During an emergency, untreated river water was used to cool the units for about 48 h. Several weeks later, five of the coolers failed by massive chloride stress-corrosion cracking. There was a large buildup of dried mud in the units, which caused reduced heat transfer and higher tube wall temperatures.

Vacuum Pumps. Liquid ring vacuum pumps typically have ductile cast iron rotors and gray cast iron casings. From a corrosion standpoint, it is desirable to use fresh seal water. Paper machine white water is considered unsuitable for seal water use because of its high temperature and low pH. Even fresh water may be corrosive if the flow rate is so low that the temperature increases inside the pump or if the fresh water becomes contaminated by excessive white water carryover. A discharge seal water temperature of 50 °C (122 °F) and/or a pH less than 4.5 can cause accelerated cast iron corrosion. High discharge seal water conductivity

Corrosion Behavior of Various Metals and Alloys in Viscose (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
317LN	S31725	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
321	S32100	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
329	S32900	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
347	S34700	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
403	S40300	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
405	S40500	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
409	S40900	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
410	S41000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
416	S41600	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
420	S42000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
430	S43000	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
434	S43400	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253
F51	S31803	...	...	Over 100% H_2SO_4	70 (158)	...	Poor	...	253

Water

Water, H_2O, is a clear, odorless, tasteless liquid that is essential for most animal and plant life and is an excellent solvent for many substances. Water has a melting point of 0 °C (32 °F) and a boiling point of 100 °C (212 °F). This chemical compound may also be termed hydrogen oxide.

Naturally occurring waters are seldom pure. Even rainwater, which is distilled by nature, contains nitrogen, oxygen, carbon dioxide, and other gases, as well as entrained dust and smoke particles. Water that runs over the ground carries with it eroded soil, decaying vegetation, living microorganisms, dissolved salts, and colloidal and suspended matter. Water that seeps through soil contains dissolved carbon dioxide and becomes acidic. Groundwater also contains salts of calcium, magnesium, iron, and manganese.

All of these foreign substances in natural water affect the structure and composition of the resulting films and corrosion products on the surface of metals, which in turn control the corrosion of the metal involved. In addition to these substances, such factors as pH, time of exposure, temperature, motion, and fluid agitation influence the aqueous corrosion of the metal.

Cooling Water. The quality of water used in shell and tube heat exchangers can vary from season to season and year to year, particularly if the water is taken from a river that discharges into a bay or sea. In one case, for example, a plant had 64 identical AISI type 304 stainless steel condensers that were cooled on the shell side with river water that varied in chloride content from less than 50 ppm to as high as 2000 ppm. The stainless steel tubes failed by external pitting at the baffles. It was discovered that an almost perfect correlation could be obtained by plotting the average monthly chloride content against the number of leaking condensers retubed that month.

In a similar case, a series of stainless steel heat exchangers cooled with recirculating treated water had been in service for more than 10 years. During an emergency, untreated river water was used to cool the units for about 48 h. Several weeks later, five of the coolers failed by massive chloride stress-corrosion cracking. There was a large buildup of dried mud in the units, which caused reduced heat transfer and higher tube wall temperatures.

Vacuum Pumps. Liquid ring vacuum pumps typically have ductile cast iron rotors and gray cast iron casings. From a corrosion standpoint, it is desirable to use fresh seal water. Paper machine white water is considered unsuitable for seal water use because of its high temperature and low pH. Even fresh water may be corrosive if the flow rate is so low that the temperature increases inside the pump or if the fresh water becomes contaminated by excessive white water carryover. A discharge seal water temperature of 50 °C (122 °F) and/or a pH less than 4.5 can cause accelerated cast iron corrosion. High discharge seal water conductivity

may indicate excessive white water carryover. Accelerated impeller corrosion can occur at rotor tip speeds above 27 m/s (80 ft/s). The presence of sand or grit in the water will also shorten liquid ring vacuum pump life because of erosion.

Material Summaries

The following material summaries were compiled from a survey of the available literature. Inclusion of a material description under a given environment does not imply that it is the most appropriate material for corrosion service in that environment. Likewise, exclusion of a given material does not imply that it is not suitable for corrosion service applications in that environment.

Aluminum. Suitability of the more corrosion-resistant aluminum alloys for use with high-purity water at room temperature is well established. The slight reaction with water that occurs initially ceases almost completely within a few days after development of a protective oxide film of equilibrium thickness. After this conditioning period, the amount of metal dissolved by the water becomes negligible.

Corrosion resistance of aluminum alloys in high-purity water is not significantly decreased by dissolved carbon dioxide or oxygen in the water or, in most cases, by the various chemicals added to high-purity water in the steam power industry to provide the required compatibility with steel. These additives include ammonia and neutralizing amines for pH adjustment to control carbon dioxide, hydrazine and sodium sulfate to control oxygen, and filming amines (long-chain polar compounds) to produce nonwettable surfaces. Somewhat surprisingly, the effects of alloying elements on corrosion resistance of aluminum alloys in high-purity water at elevated temperatures are opposite to their effects at room temperature; elements (including impurities) that decrease resistance at room temperature improve it at elevated temperatures.

At 200 °C (390 °F), high-purity aluminum of sheet thickness disintegrates completely within a few days by reaction with high-purity water to form aluminum oxide. In contrast, aluminum-nickel-iron alloys have the best elevated temperature resistance to high-purity water of all aluminum metals; for example, alloy X8001 (1.0Ni-0.5Fe) has good resistance at temperatures as high as 315 °C (600 °F).

Erosion-Corrosion. In noncorrosive environments such as high-purity water, the stronger aluminum alloys have the greatest resistance to erosion-corrosion, because resistance is controlled almost entirely by the mechanical components of the system. In a corrosive environment, such as seawater, the corrosion component becomes the controlling factor; thus, resistance may be greater for the more corrosion-resistant alloys even though they are lower in strength.

Stress-Corrosion Cracking. Water or water vapor is the key environmental factor required to produce stress-corrosion cracking in aluminum alloys. Halide ions have the greatest effects in accelerating attack. Chloride is the most important halide ion because it is a natural constituent of marine environments and is present in other environments as a contaminant. Because it accelerates stress-corrosion cracking, Cl^- is the principal component of environments used in laboratory tests to determine susceptibility of aluminum alloys to this type of attack. In general, susceptibility is greater in neutral solutions than in alkaline solutions and is greater still in acidic solutions.

Natural Waters. Aluminum alloys of the 1*xxx*, 3*xxx*, 5*xxx*, and 6*xxx* series are resistant to corrosion by many natural waters. The more important factors controlled the corrosivity of natural waters to aluminum include water temperature, pH, and conductivity, availability of cathodic reactants, presence or absence of heavy metals, and the corrosion potentials and pitting potentials of the specific alloys. Various correlations of the corrosivity of natural waters to aluminum have been attempted, but none predicts the corrosivity of all natural waters reliably.

Beryllium. Beryllium that is clean and free of surface impurities has very good resistance to attack in low-temperature high-purity water. The corrosion rate in good-quality water is typically less than 0.025 mm/yr (1 mil/yr).

Beryllium has been reported to perform without problems for 10 years in slightly acidified demineralized water in a nuclear test reactor. This high-purity water environment also produced no evidence of accelerated corrosion with the beryllium galvanically coupled with stainless steel or aluminum.

Beryllium of normal commercial purity, however, is susceptible to attack, primarily in the form of localized pitting, when exposed to impure water. Chloride and sulfate ions are the most critical contaminants in aqueous solutions. Because these contaminants are present in the tap water, most processing specifications warn against its use. Early processors encountered serious problems of pitting or surface corrosion in beryllium that was allowed to stand in tap water, or was rinsed off with tap water and, after drying, was allowed to stand in a damp atmosphere where water condensation could easily occur on the contaminated surfaces. More recently, an airframe manufacturer experienced a major production problem when water vapor, condensing on overhead piping, dripped onto structures in the processing line. In cases where tap water can be used, the final rinses are done in deionized water to ensure that the chloride or sulfate impurities are not retained on the subsequently dried metal surface.

The pitting of beryllium in aqueous baths containing chloride or sulfate ions has generally been attributed to attack in areas anodic to the bulk of the metal. In an investigation consisting of 12-month corrosion tests in water at 85 °C (185 °F), the pitting attack was attributed to a lack of metal purity. Years later, in a study prompted by rejection of beryllium components for the presence of hard inclusions, pitting corrosion was shown to be associated with points of silicon and aluminum segregation.

On the basis of the examination of pitted specimen surfaces by microprobe analysis, the following general conclusions were drawn:

- Pitting corrosion is determined by the distribution of alloy impurities.
- Sites that have high concentrations of iron, aluminum, or silicon (probably in solid solution) tend to form corrosion pits.
- Corrosion sites are often characterized by the presence of alloy-rich particles, which are probably beryllides; however, the particles themselves do not appear to be corrosion active.
- Pitting density is believed to be related to the number of segregated regions in the matrix containing concentrations of iron, aluminum, or silicon higher than concentrations present in the surrounding areas.

Segregated impurities, such as Be_2C particles, intermetallic compounds, or alloy-rich zones, can contribute to localized attack when present in an exposed beryllium surface. Be_2C forms a gelatinous corrosion product in an aqueous environment. As the purity of beryllium has improved during the years of its commercialization, the problem of localized corrosion at segregated particles and inclusions has significantly decreased.

The effects of the surface finish of beryllium on aqueous corrosion were investigated. The specimen conditions included (1) as-machined, (2) pickled in chromic-phosphoric acid after machining, and (3) machined, annealed beryllium reannealed in vacuum for 1 h at 825 °C (1515 °F). The results of long-term tests in demineralized water at 85 °C (185 °F) showed that the pickled specimens corroded at a higher rate than the others during the first 60 days of testing. The machined and annealed specimens initially corroded faster than the as-machined specimens. It was found, however, that with extended exposure times the magnitude of attack for all the types of surfaces reached about the same value—0.0025 to 0.005 mm/yr (0.1 to 0.2 mil/yr).

Extensive information on the behavior of beryllium under the combined effects of stress and chemical environment is not readily available. The first reported work involved the use of extruded material in water containing 0.005*M* hydrogen peroxide at pH 6 to 6.5 at 90 °C (195 °F). No evidence of cracking was noted even though stresses up to 90% of the yield strength were used. Stress corrosion has been reported on cross-rolled sheet when synthetic seawater was used as the test medium. Studies of time to failure versus applied stress revealed that the time decreased from 2340 to 40 h as the applied stress was increased from 8.4 to 276 MPa (1220 to 40,000 psi, or 70% of yield strength). Failure appeared to be closely associated with random pitting attack. Certain pits appeared to remain active, which promoted severe localized attack.

Cast Irons. Unalloyed and low-alloy cast irons are the primary cast irons used in water. The corrosion resistance of unalloyed cast iron in water is determined by its ability to form protective scales. In hard water, corrosion rates are generally low because of the formation of calcium carbonate scales on the surface of the iron. In softened or deionized water, the protective scales cannot be fully developed, and some corrosion will occur.

In industrial waste waters, corrosion rates are primarily a function of the contaminants present. Acid pH waters increase corrosion, but alkaline pH waters lower corrosion rates. Chlorides increase the corrosion rates of unalloyed cast irons, although the influence of chlorides is small at a neutral pH.

Carbon Steels. Carbon steel pipe and vessels are often required to transport water, or they are submerged in water to some extent during service. This exposure can be under conditions of varying temperature, flow rate, pH, and so on, all of which can alter the rate of corrosion. The relative acidity of the solution is probably the most important factor to be considered. At low pH, the evolution of hydrogen tends to eliminate the possibility of protective film formation so that steel continues to corrode, but in alkaline solutions, the formation of protective films greatly reduces the corrosion rate. The greater the alkalinity, the slower the rate of attack becomes. In neutral solutions, other factors, such as aeration, become rate determining so that generalization becomes more difficult.

Stainless Steels. The chloride contents of waters such as brackish water or seawater pose the danger of pitting or crevice corrosion of stainless steels. When the application involves moderately increased temperatures, even as low as 45 °C (110 °F), and particularly when there is heat transfer into the chloride-containing medium, there is the possibility of stress-corrosion cracking. It is useful to consider water with two general levels of chloride content—fresh water, which can have chloride levels up to approximately 600 ppm, and seawater, which encompasses brackish and severely contaminated waters. The corrosivity of a particular level of chloride can be strongly affected by the other chemical constituents present, making the water either more or less corrosive.

Permanganate ion, which is associated with the dumping of chemicals, has been related to pitting of type 304 stainless steel. The presence of sulfur compounds and oxygen or other oxidizing agents can affect the corrosion of copper and copper alloys, but does not have very significant effects on stainless steels at ambient or slightly elevated temperatures (up to approximately 250 °C, or 500 °F).

In fresh water, type 304 stainless steel has provided excellent service for such items as valve parts, wires, fasteners, and pump shafts in water and wastewater treatment plants. Custom 450 stainless steel has been used as shafts for large butterfly valves in potable water. The higher strength of precipitation-hardenable stainless steel permits reduced shaft diameter and increased flow. Type 201 stainless steel has seen service in revetment mats to reduce shoreline erosion in fresh water. Type 316 stainless steel has been used as wire for microstrainers in tertiary sewage treatment and is suggested for waters containing minor amounts of chloride.

Cemented Carbides. The major applications of cemented carbides actually involve environments that are inherently corrosive. For example, the major use of cemented carbides is for metal-cutting (machining) applications. In these applications, extreme heat is generated whether or not coolants are used, and when coolants are used, the corrosive attack of the coolant is a factor in the performance of the cutting tool. In general, however, very little heed is paid to this factor; cemented carbides are more often chosen for their wear resistance in such applications as mining and oil well drilling. In actuality, there is a corrosive environment to be contended within mining and oil well drilling; the natural waters and other fluids involved are often very corrosive.

Copper. Copper is extensively used for handling fresh water. Copper tubing in the K-gage range with flared fittings was designed for underground water service and, along with type L tubing, has not become standard for this application. The largest single application of copper tubing is for hot and cold water distribution lines in homes and other buildings, although considerable quantities are also used in heating lines (including radiant heating lines for homes), drain tubes, and fire safety systems.

Minerals in water combine with dissolved carbon dioxide and oxygen and react with copper to form a protective film. Therefore, the corrosion rate is low (5 to 25 μm/yr, or 0.2 to 1.0 mil/yr) in most exposures. In distilled water or very soft water, protective films are less likely to form; therefore, the corrosion rate may vary from less than 2.5 to 125 μm/yr (0.1 to 5 mil/yr) or more, depending on oxygen and carbon dioxide contents.

Copper-Zinc Alloys. The corrosion resistance of the brasses is good in unpolluted fresh water—normally 2.5 to 25 m/yr (0.1 to 1.0 mil/yr). Corrosion rates are somewhat higher in nonscaling water containing carbon dioxide and oxygen. Uninhibited brasses of high zinc content (35 to 40% Zn) are subject to dezincification when used with stagnant or slow moving brackish or slightly acid waters. On the other hand, inhibited admiralty metals and brasses containing 15% Zn or less are highly resistant to dezincification and are used very successfully in these waters. Inhibited admiralty metal (C44300, C44400, and C44500) has good corrosion resistance and is extensively used for tubing in various services, especially steam condensers cooled with fresh, salt, or brackish water. Several cases of the stress-corrosion cracking of admiralty brass heat exchanger tubing have been documented. The environments in which such stress-corrosion cracking was observed included stagnant water, stagnant water contaminated with NH_3, and water accidentally contaminated with a nitrate. Inhibited yellow brasses are widely used in Europe and are gaining acceptance in North America. Alloy C68700

(arsenical aluminum brass, an inhibited 77Cu-21Zn-2Al alloy) has been successfully used for condenser and heat exchanger tubes.

Copper Nickels. Copper nickels generally have corrosion rates under 25 m/yr (1 mil/yr) in unpolluted water. Alloy C71500 (Cu-30Ni) has the best general resistance to aqueous corrosion of all the commercially important copper alloys, but C70600 (Cu-10Ni) is often selected because it offers good resistance at lower cost. Both of these alloys, although well suited to applications in the chemical industry, have been most extensively used for condenser tubes and heat exchanger tubes in recirculating steam systems. Copper nickels are sometimes used to resist impingement attack where severe velocity and entrained-air conditions cannot be overcome by changes in operating conditions or equipment design.

Copper-Silicon Alloys. Copper-silicon alloys (silicon bronzes) also have excellent corrosion resistance, and for these alloys, the amount of dissolved oxygen in the water does not influence corrosion significantly. If carbon dioxide is also present, the corrosion rate will increase (but not excessively), particularly at temperatures above 60 °C (140 °F). Corrosion rates for silicon bronzes are similar to those for copper.

Copper-Aluminum Alloys. The aluminum bronzes have been used in many waters, from potable water to brackish water to seawater. Softened waters are usually more corrosive to these materials than hard waters. Alloys C61300 and C63200 are used in cooling toward hardware in which the makeup water is sewage effluent. Aluminum bronzes resist oxidation and impingement corrosion because of the aluminum in the surface film.

Nickel Silvers. The two most common nickel silvers—C75200 (65Cu-18Ni-17Zn) and C77000 (55Cu-18Ni-27Zn)—have good resistance to corrosion in fresh water.

Hafnium. The corrosion resistance of hafnium in water is superior to that of zirconium and Zircaloy alloys.

Lead. Distilled water free of oxygen and carbon dioxide does not attack lead. Distilled water containing carbon dioxide but not oxygen also has little effect on lead. The corrosion behavior of lead in distilled water containing dissolved carbon dioxide and dissolved oxygen depends on the carbon dioxide concentration. This dependency, which causes may different reactions to take place in a narrow range of concentration, explains the contradictory nature of much of the corrosion data reported in the literature.

For example, lead steam coils that handle pure water condensate are not severely corroded in systems in which all condensate is returned to the boiler and negligible makeup water is used. However, if makeup water is used, dissolved oxygen can be introduced to the condensate, and corrosion can be severe. Carbon dioxide can also be generated from the breakdown of carbonates and bicarbonates in boiler water, decreasing the severity of corrosion of lead. The oxygen level in the makeup water is usually controlled by adding oxygen scavengers, such as hydrazine or sodium sulfite.

In general, the corrosion rate in natural and domestic waters depends on the degree of water hardness. Water hardness is primarily caused by calcium and magnesium salts in the water. These salts, if present in at least moderate amounts (>125 ppm), form films on lead that adequately protect against corrosive attack. Silicate salts present in the water increase both the hardness and the protective value of the film. In contrast, nitrate and chloride ions either interfere with the formation of the protective film or penetrate it, thus increasing corrosion.

In soft, aerated natural and domestic waters, the corrosion rate depends on both the hardness and the oxygen content of the water. When water hardness is less than 125 ppm, the corrosion rate, like the rate in distilled water, depends on the relative proportions of dissolved carbon dioxide and dissolved oxygen. Potable waters, in which lead content is not permitted to exceed 0.05 ppm, often have hardnesses below 125 ppm and often contain considerable amounts of carbon dioxide and oxygen; thus, lead frequently cannot be used for pipe or containers that handle potable waters. This problem of contamination limits the use of lead in such applications, even though from a service point of view, the corrosion rate is negligible.

The corrosion rates of chemical lead (99.9% Pb) in several industrial and domestic waters were investigated. It was found that corrosion rates were relatively low, even where water hardness was below 125 ppm.

Magnesium. In stagnant distilled water at room temperature, magnesium alloys rapidly form a protective film that prevents further corrosion. Small amounts of dissolved salts in water, particularly chlorides or heavy metal salts, will break down the protective film locally, which usually results in pitting.

Dissolved oxygen plays no major role in the corrosion of magnesium in either fresh water or saline solutions. However, agitation or any other means of destroying or preventing the formation of a protective film leads to corrosion. When magnesium is immersed in a small volume of stagnant water, its corrosion rate is negligible. When the water is constantly replenished so that the solubility limit of $Mg(OH)_2$ is never reached, the corrosion rate may increase.

The corrosion of magnesium alloys by pure water increases substantially with temperature. At 100 °C (212 °F), the AZ alloys corrode typically at 0.25 to 0.50 mm/yr (10 to 20 mils/yr). Pure magnesium and alloy ZK60A corrode extensively at 100 °C (212 °F) with rates up to 25 mm/yr (1000 mils/yr). At 150 °C (302 °F), all alloys corrode excessively.

Nickel. Nickel and nickel-base alloys generally have very good resistance to corrosion in distilled water and fresh water. Typical corrosion rates for Nickel 200 (commercially pure nickel) in a distilled water storage tank at ambient temperature and domestic hot water service are <0.0025 mm/yr (<0.1 mil/yr) and <0.005 mm/yr (<0.2 mil/yr), respectively. Nickel-copper alloys such as 400 and R-405 also have very low corrosion rates and are used in fresh water systems for valve seats and other fittings.

Because of the cost of nickel alloys, less expensive stainless steels or other materials are usually specified for pure or freshwater applications, unless increased resistance to stress-corrosion cracking or pitting is required. Alloys 600 and 690, for example, are used for increased stress-corrosion cracking resistance in high-purity water nuclear steam generators. Stress-corrosion cracking of these alloys has occurred in such environments and is generally intergranular. This phenomenon also extends to stainless steels and other nickel-base alloys. Although alloy 600 is susceptible to cracking in steam generators, it is much more resistant than type 304 stainless steel.

Niobium. Niobium reacts with water to form niobium oxide. There is a direct transition from immunity to passivity without an intermediate region where corrosion occurs. Niobium reacts with water vapor and temperatures above 300 °C (570 °F).

Silver. Silver is resistant to attack by water or steam temperatures up to 600 °C (1110 °F).

Tantalum. Tantalum is not attacked by fresh water, mine waters (which are usually acidic), or seawater, either cold or hot. Tantalum shows no corrosion in deionized water at 40 °C (100 °F). For tantalum equipment exposed to boiler waters and condensates, the alkalinity must be controlled. The pH should be less than 9 and preferably no more than 8.

Tin. In hot or cold distilled water, the only action of tin is the slow growth of an oxide film, with a negligible amount of metal entering solution. Water that was freshly distilled in tin was found to have less than 1 ppb tin in solution. Storage in tin-lined or tinned copper tanks for 24 h produced, in the worst instances, only a few ppb, but in some cases, the tin content remained below 1 ppb.

In tap water of 7.2 pH at 25 °C (75 °F), specimens of 99.99% cold rolled tin showed a weight gain of 0.04 mils/yr in 50 days and the formation of an insoluble film. With harder tap waters of 7.4 and 8.6 pH, weight losses on the order of 0.09 and 0.02 mils/yr, respectively, were incurred in 50 days. Precipitated carbonate was mainly responsible for localized water line attack with hot or cold waters because no attack occurred without the precipitate.

Tin-Lead Solders. Natural waters and commercial treated waters that are aggressive to lead are likely to corrode solder at a rate that increases slowly, in proportion to its lead content, up to about 70% Pb, then more rapidly at higher lead contents. Selective dissolution of lead can also occur in distilled, demineralized, or naturally soft waters, causing serious weakening of joints. In commercial waters, the ability of lead to form insoluble oxides, sulfates, and carbonates usually protects solders against serious attack. Although rare, selective dissolution of tin has been reported during prolonged contact with solders with solutions of anionic surface-active agents.

When freshly exposed to water, solders are anodic to copper, but soldered joints in copper pipes are widely used without trouble in conventional commercial and domestic cold and hot water systems. Despite this generally good corrosion resistance, it has been demonstrated that, under adverse conditions, lead may be leached from the commonly used 50Sn-50Pb plumbing solder into water traveling through the pipe; this is a cause of increasing concern.

Soldered joints in brass usually perform well in domestic waters, but good joint design is imperative. In automobile radiators in which there are no inhibitors, ethylene glycol, although not directly aggressive, does appear able to detach protective deposits that may form on soldered joints. Sodium nitrite, which is used as an inhibitor for some metals, will attack solders and must be used in conjunction with sodium benzoate.

Titanium. Titanium and its alloys are fully resistant to water, all natural waters, and steam at temperatures in excess of 315 °C (600 °F). Slight weight gain is usually experienced in these benign environments, along with some surface discoloration at higher temperatures from finite passive film thickening. The immunity to attack of alpha alloys is observed regardless of oxygen level or in high-purity water, such as that normally used in nuclear reactor coolant systems. The typical contaminants encountered in natural water streams, such as iron and manganese oxides, sulfides, sulfates, carbonates, and chlorides, do not compromise the passivity of titanium. In media containing chloride levels greater than 1000 ppm (for example, seawater) at temperatures of about 75 °C (165 °F), consideration should be given to possible crevice corrosion when tight crevices exist in service.

Stress-Corrosion Cracking. Under certain metallurgical conditions, several titanium alloys have been shown to be susceptible to stress-corrosion cracking in distilled water. These include Ti-8Al-1Mo-1V, Ti-5Al-2.5Sn, and Ti-11.5Mo-6Zr-4.5Sn. Microstructural variation for each alloy affects the degree of susceptibility. For example, mill-annealed Ti-8Al-1Mo-1V is less susceptible than step-cooled Ti-8Al-1Mo-1V.

Stress-corrosion cracking of Ti-8Al-1Mo-1V has been extensively studied because of its sensitivity to microstructure. The martensitic structures produced by quenching from a high-temperature solution treatment are immune to stress-corrosion cracking. Lower temperature solution treatment produces an equiaxed alpha-beta structure that is susceptible to stress-corrosion cracking. The degree of susceptibility is determined by the grain size, volume fraction, and mean free path of the susceptible alpha phase. Tempered martensitic structures, produced by annealing a martensitic microstructure, are also susceptible to stress-corrosion cracking. Basket-weave or Widmanstätten microstructures produced by working and/or heat treatment above the beta transus generally exhibit better toughness both in and out of an aqueous environment.

In general, titanium alloys with higher aluminum, oxygen, and tin contents are the most susceptible to stress-corrosion cracking. Molybdenum is usually beneficial in increasing stress-corrosion cracking resistance. Microstructural effects in these alloys are similar to those discussed for Ti-8Al-1Mo-1V.

With the exception of Ti-13V-11Cr-3Al, all of the commercial beta titanium alloys are immune to stress-corrosion cracking in the beta-phase condition. However, aging decomposes the beta phase and produces a variety of phases. The omega phase produced by low-temperature aging of many beta alloys does not induce stress-corrosion cracking susceptibility. Aging at higher temperatures produces the alpha phase, which nearly always leads to stress-corrosion cracking. The degree to which a given beta alloy in the beta + alpha condition is susceptible appears to be related to the alloy chemistry and to the quantity and morphology of the alpha phase.

Aging at higher temperatures produces a coarser alpha, which is less susceptible to stress-corrosion cracking than the finer alpha. Alloys containing molybdenum are less susceptible to stress-corrosion cracking, especially those without tin.

Ionic Species. The anions Cl^-, Br^-, and I^- are some of the species shown to promote and/or induce stress-corrosion cracking in titanium alloys. The few alloys susceptible to cracking in distilled water become more susceptible, whereas alloys that are not susceptible in distilled water may become susceptible when these species are present.

Zinc. The corrosion of zinc in water is largely controlled by the impurities present in the water. In addition, such factors as pH, time of exposure, temperature, motion, and fluid agitation influence the aqueous corrosion of zinc.

As in the atmosphere, the corrosion resistance of a zinc coating in water depends on its initial ability to form a protective layer by reacting with the environment. In distilled water, which cannot form a protective scale to reduce the access of oxygen to the zinc surface, the attack is more severe than in most types of domestic or river water, which do contain some scale-forming salts.

The scale-forming ability of water depends principally on three factors: the hydrogen ion concentration (pH value), the total calcium content, and the total alkalinity. If the pH value is below that at which the water would be in equilibrium with calcium carbonate, the water will tend to dissolve rather than to deposit scale. Waters with a high content of free carbon dioxide also tend to be aggressive toward zinc.

Water hardness is an important variable in zinc corrosion. The corrosion rate of zinc in hard water may be 15 μm/yr (0.6 mil/yr), but in soft water, it can be 150 μm/yr (6 mils/yr). Hard waters are usually less corrosive toward zinc because they deposit protective scales on the metallic surface. Softer waters do not deposit these scales. Similarly, seawater also deposits protective scales on zinc and is less corrosive than soft water.

Softer waters, with their higher content of dissolved oxygen and carbon dioxide, generally attack zinc more vigorously than the fairly hard waters. River waters have been found to deposit scale more easily than well waters. The normal corrosion product of zinc in water is $ZnCO_3$.

Agitation, Aeration, and Carbon Dioxide. With respect to distilled water, under conditions in which the oxygen content cannot be replaced as quickly as it is consumed by the corrosion process, such as in stagnant water, zinc is attacked rapidly at local areas, and this causes pitting. As more oxygen is made available, the corrosion becomes more uniform. With further increases in the oxygen content of the water, the corrosion rate increases. For example, when thin films of moisture condense on a zinc surface, the concurrent rapid supply of oxygen at the corroding surface has an accelerating effect on the corrosion rate.

Experimentation has shown that with test pieces immersed in water through which oxygen was bubbled corrosion occurred about eight times as fast as with specimens in water that was boiled to remove gases and then cooled out of contact with air. Although the corrosion rate increased when oxygen was bubbled through the water, the attack was uniform. The presence of oxygen in the water accelerates the corrosion by depolarization of the cathodic areas. The rate of corrosion is then controlled by diffusion of oxygen through the film of $Zn(OH)_2$ corrosion products.

Temperature. In practical applications involving distilled water, the temperature of the water has been shown to be a very important factor affecting the rate of corrosion of zinc. In one study, a marked increase in corrosion rate was found to occur at a temperature of about 60 °C (140 °F), followed by a decrease in corrosion at higher temperature. At temperatures near 70 °C (160 °F), a reversal in potential may occur where zinc coatings become cathodic to iron. Low oxygen and high bicarbonate contents favor reversal, but the presence of oxygen, sulfates, and chlorates tends to maintain the natural anodic state of the zinc.

The results of this study were obtained on 99.9% pure zinc immersed for 15 days in aerated distilled water. The water was continuously aerated by air bubbling through it, and no attempt was made to remove carbon dioxide from the air. Also, the specimens were supported on a wooden disk that was rotated through the test water at 56 rpm. Thus, all of the factors that cause increased corrosion, as discussed above, were present in these tests. The temperature, however, seems to have been the controlling factor in this experiment.

Tests showed that the observed corrosion peak at approximately 65 °C (150 °F) occurs both in waters under a pure oxygen atmosphere and under a carbon dioxide free air atmosphere. In contrast, under an oxygen-free nitrogen atmosphere, the peak disappears completely. Additional experiments showed that, as the partial pressure of oxygen over the water was reduced from that in air, the peak decreased in magnitude and shifted to lower temperatures that involve the decreased solubility of oxygen in water at elevated temperatures.

This is consistent with the observation that decreased oxygen supplies (caused by reduced oxygen pressure over the water) lower the corrosion peak temperature. As the oxygen partial pressure is lowered, the equilibrium oxygen content in the water is lowered for any temperature. The reduced oxygen content of thus lowers the temperature at which depolarization becomes rate limiting, because the critical oxygen level for depolarization is reached at a lower temperature.

Cold Domestic Water. Galvanized pipe is widely used in handling domestic water supplies, and the results have been satisfactory. Therefore, quantitative corrosion rates are not of primary interest, and only limited data are available in the literature. Hard domestic waters contain dissolved salts that may affect the corrosion of zinc. Carbonates and bicarbonates tend to deposit protective films that stifle corrosion, and it is generally agreed that soft or distilled waters are more corrosive than hard water.

Hot Domestic Water. In domestic water systems, for which zinc is widely adopted as a protective coating, the sacrificial dissolution of zinc at discontinuities in the coating in the presence of calcium bicarbonate (a normal constituent of hard water supplies) leads to the deposition of an insoluble layer of $CaCO_3$ on the exposed surfaces. Because this layer is impervious to the passage of ions and electrons, it inhibits any further corrosive action. This reaction, which depends on all presence of dissolved calcium bicarbonate in the water, cannot occur in systems in soft water areas, and it is generally agreed that soft or distilled water is more corrosive than hard water. Other constituents in natural waters, such as nitrates, sulfates, and chlorides, may tend to increase corrosion, but their effects are usually overcome by the carbonates that form films of relatively low solubility in close contact with the zinc surface.

Changing the temperature of a solution can influence the corrosion tendency. For example, historically, household water heater tanks were made of galvanized steel. The zinc coating on the carbon steel base offered some cathodic protection to the underlying steel, and the service life (usually judged by how long it took to produce rusty water) was considered to be adequate. Water tanks were seldom operated above 60 °C (140 °F).

Natural Water. The factors influencing the corrosion of zinc by tap or supply waters discussed in the preceding paragraphs also apply to natural waters, such as lake and river waters.

Zirconium. Corrosion and oxidation of unalloyed zirconium in water and steam are reported to be irregular. This behavior is probably caused by variations in the impurity content in the metal. Nitrogen and carbon impurities are particularly harmful. The corrosion rate of zirconium increases markedly when nitrogen and carbon concentrations exceed 40 and 300 ppm, respectively.

Zircaloy-2 is superior to unalloyed zirconium in high-temperature water and steam. Zircaloy-4 differs in composition from Zircaloy-2 only in that it has no nickel and a slightly greater iron content. Both variations are intended to reduce hydrogen pickup in reactor operation. The corrosion behavior of Zircaloy-4 is very similar to that of Zircaloy-2. However, hydrogen pickup for Zircaloy-4 is significantly lower, particularly when the alloy is exposed to water at 360 °C (680 °F). At this temperature, hydrogen pickup for Zircaloy-4 is about 25% of theoretical, or less than half that for Zircaloy-2. In addition, hydrogen pickup for Zircaloy-4 is less sensitive to hydrogen overpressure than that for Zircaloy-2. For both Zircaloys, hydrogen pickup is markedly decreased when dissolved oxygen is present in the corrosion medium.

Alloy Zr-2.5Nb is considered to be somewhat less resistant to corrosion than the Zircaloys. Nevertheless, Zr-2.5Nb is acceptable for many applications. An example is the use of Zr-2.5Nb pressure tubes in the primary loops of some reactors. The corrosion resistance of Zr-2.5Nb can be substantially improved by heat treatment. Also, Zr-2.5Nb is superior to Zircaloys in steam at temperatures above 400 °C (750 °F).

Corrosion Behavior of Various Metals and Alloys in Water

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Aluminum and alloys									
Aluminum (>99.5%)	A91350	...	Fresh tap water	...	...	...	Resistant	...	92
Carbon and alloy steels									
Carbon steel	G10100	...	Clean Mississippi water	...	...	...	0.09 (3.61) max	...	179
Carbon steel	G10100	...	Natural hard water	...	...	...	0.15 (6.0)	...	179
Carbon steel	G10100	...	Polluted Monongahela water	...	...	...	0.15 (6.0) max	...	179
MF-1 carbon steel	...	...	Clean Mississippi water	...	...	...	0.03 (1.0)	...	179
MF-1 carbon steel	...	...	Natural hard water	...	...	...	Resistant	...	179
MF-1 carbon steel	...	...	Polluted Monongahela water	...	...	...	0.03 (1.0)	...	179
Mild steel	G10100	...	Cooling tower water containing 7.4 mM Ca, 7.3 mM "M" alkalinity, 2.33 mM SiO_2, Aerated, pH 9.1	...	38 (100)	...	.027 (1.1)	...	248
Mild steel	G10100	...	Cooling tower water containing 7.4 mM Ca, 7.3 mM "M" alkalinity, 2.33 mM SiO_2, Plus 0.1 mg/L ozone, pH 8.8	...	38 (100)	...	.018 (0.7)	...	248
Mild steel	G10100	...	Cooling tower water containing 7.4 mM Ca, 7.3 mM "M" alkalinity, 2.33 mM SiO2 Plus 1 mg/L ozone, pH 7.2	...	38 (100)	...	.12 (4.5)	...	248
Copper and alloys									
70-30 cupronickel	C71500	...	Carbonated	...	...	...	Good	...	93
70-30 cupronickel	C71500	...	Potable	...	...	...	Resistant	...	93
90-10 cupronickel	C70600	...	Carbonated	...	...	...	Good	...	93
90-10 cupronickel	C70600	...	Potable	...	...	...	Resistant	...	93
Admiralty brass	C44300	...	Carbonated	...	...	...	Good	...	93
Admiralty brass	C44300	...	Potable	...	...	...	Resistant	...	93
Aluminum bronze	...	...	Carbonated	...	...	...	Good	...	93
Aluminum bronze	...	...	Potable	...	...	...	Resistant	...	93
Ampco 8, aluminum bronze	C61300	...	Fresh	...	...	...	0.05 (2) max	...	96
Ampco 8, aluminum bronze	C61300	...	Salt	...	...	...	0.05 (2) max	...	96
Architectural bronze	C38500	...	Carbonated	...	...	...	Questionable	...	93
Architectural bronze	C38500	...	Potable	...	...	...	Questionable	...	93
Brass	...	...	Carbonated	...	...	...	Good	...	93
Brass	...	...	Potable	...	...	...	Resistant	...	93
Cartridge brass	C26000	...	Carbonated	...	...	...	Questionable	...	93
Cartridge brass	C26000	...	Potable	...	...	...	Questionable	...	93
Commercial bronze	C22000	...	Carbonated	...	...	...	Good	...	93
Commercial bronze	C22000	...	Potable	...	...	...	Resistant	...	93
Electrolytic copper	C11000	...	Carbonated	...	...	...	Good	...	93
Electrolytic copper	C11000	...	Potable	...	...	...	Resistant	...	93
Free-cutting brass	C36000	...	Carbonated	...	...	...	Questionable	...	93
Free-cutting brass	C36000	...	Potable	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Carbonated	...	...	...	Questionable	...	93
Muntz metal	C28000	...	Potable	...	...	...	Questionable	...	93
Naval brass	C46400	...	Carbonated	...	...	...	Questionable	...	93
Naval brass	C46400	...	Potable	...	...	...	Questionable	...	93
Nickel-silver	...	...	Carbonated	18	...	...	Good	...	93
Nickel-silver	...	...	Potable	18	...	...	Resistant	...	93
Phosphor bronze, 5% Sn	C51000	...	Carbonated	...	...	...	Good	...	93
Phosphor bronze, 5% Sn	C51000	...	Potable	...	...	...	Resistant	...	93
Phosphor bronze, 8% Sn	C52100	...	Carbonated	...	...	...	Good	...	93
Phosphor bronze, 8% Sn	C52100	...	Potable	...	...	...	Resistant	...	93
Phosphor copper	C12200	...	Carbonated	...	...	...	Good	...	93

(Continued)

Corrosion Behavior of Various Metals and Alloys in Water (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Phosphor copper	C12200	...	Potable	...	...	...	Resistant	...	93
Red brass	C23000	...	Carbonated	...	...	...	Good	...	93
Red brass	C23000	...	Potable	...	...	...	Resistant	...	93
Silicon bronze, high	C65500	...	Carbonated	...	...	...	Good	...	93
Silicon bronze, high	C65500	...	Potable	...	...	...	Resistant	...	93
Silicon bronze, low	C65100	...	Carbonated	...	...	...	Good	...	93
Silicon bronze, low	C65100	...	Potable	...	...	...	Resistant	...	93
Miscellaneous									
Chemical lead	L51120	...	Condensed steam. Traces of acid. No aeration. Slow agitation	...	21-38 (70-100)	...	0.02 (0.9)	...	178
Chemical lead	L51120	...	Cooling tower water, oxygenated, from Lake Erie; complete aeration; no agitation	...	16-29 (60-85)	...	0.13 (5.3)	...	13
Chemical lead	L51120	...	Cooling tower, oxygenated Lake Erie water. Complete aeration. No agitation	...	16-29 (60-85)	...	0.13 (5.3)	...	178
Chemical lead	L51120	...	Los Angeles aqueduct water, treated with Cl and $CuSO_4$; 150 mm/s (0.5 ft/s) agitation	...	Ambient	...	0.01 (0.4)	...	13
Chemical lead	L51120	...	Los Angeles aqueduct water, treated with Cl and $CuSO_4$; Agitation, 0.5 ft/s	...	Ambient	...	0.01 (0.4)	...	178
Chemical lead	L51120	...	Mine water: 110 ppm hardness. Aerated. Slow agitation	...	22 (72)	...	0.008 (0.3)	...	13
Chemical lead	L51120	...	Mine water: 110 ppm hardness. Aerated. Slow agitation	...	22 (72)	...	0.008 (0.3)	...	178
Chemical lead	L51120	...	Mine water: 160 ppm hardness. Aerated. Slow agitation	...	19 (67)	...	0.008 (0.3)	...	13
Chemical lead	L51120	...	Mine water: 160 ppm hardness. Aerated. Slow agitation	...	19 (67)	...	0.008 (0.3)	...	178
Chemical lead	L51120	...	Mine water: pH 8.3, 110 ppm hardness. Aerated. Slow agitation	...	20 (68)	...	0.008 (0.3)	...	13
Chemical lead	L51120	...	Mine water: pH 8.3, 110 ppm hardness. Aerated. Slow agitation	...	20 (68)	...	0.008 (0.3)	...	178
Chemical lead	L51120	...	Spray cooling water, chromate treated, aerated	...	16 (60)	...	0.01 (0.4)	...	13
Chemical lead	L51120	...	Spray cooling water, chromate treated. Aerated	...	16 (60)	...	0.01 (0.4)	...	178
Lead (99.999%)	L50001	...	Distilled water	...	75 (167)	60 d	.57 (22.5)	...	208
Lead (99.999%)	L50001	...	Groundwater	...	75 (167)	60 d	.001 (0.04)	...	208
Lead (99.999%)	L50001	...	Oxygen saturated groundwater	...	75 (167)	60 d	.007 (0.28)	...	208
Lead (99.999%)	L50001	...	Synthetic groundwater	...	75 (167)	60 d	.003 (0.1)	...	208
Magnesium	...	...	...	100	Boiling	...	Poor	...	119
Magnesium	...	...	Distilled	100	Room	...	Resistant	...	119
Magnesium	...	...	Rain	100	Room	...	Resistant	...	119
Tin	...	...	Distilled	...	20 (68)	...	Resistant	...	94
Tin	...	...	Distilled	...	60 (140)	...	Resistant	...	94
Tin	...	...	Distilled	...	100 (212)	...	Resistant	...	94
Tin, hard	...	...	...	...	20 (68)	...	Resistant	...	94
Tin, hard	...	...	...	...	60 (140)	...	Resistant	...	94
Tin, hard	...	...	...	...	100 (212)	...	Resistant	...	94
Tin, soft	...	...	...	...	20 (68)	...	Resistant	...	94
Tin, soft	...	...	...	...	60 (140)	...	Resistant	...	94
Tin, soft	...	...	...	...	100 (212)	...	Resistant	...	94
Zinc	Z13001	...	Distilled water, aerated	...	...	30 d	0.1 (5)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	20 (68)	15 d	0.02 (0.8)	...	177

(Continued)

Corrosion Behavior of Various Metals and Alloys in Water (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	50 (122)	15 d	0.07 (2.7)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	55 (131)	15 d	0.4 (15)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	65 (149)	15 d	2.9 (115)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	75 (167)	15 d	2.3 (92)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	95 (203)	15 d	0.3 (12)	...	177
Zinc	Z13001	Rolled high-grade	Distilled water, aerated by air bubbles	...	100 (212)	15 d	0.1 (4.7)	...	177
Zinc	Z13001	...	Distilled water, aerated. Specimen rotated 6 rpm	...	...	30 d	0.1 (4.7)	...	177
Zinc	Z13001	...	Distilled water, quiet	...	...	30 d	0.1 (4.8)	...	177
Zinc	Z13001	...	Distilled water, specimen rotated	...	...	30 d	0.2 (6.4)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water	...	...	20 d	0.11 (4.2)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water	...	...	60 d	0.07 (2.9)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 0.6 mg/L CO_2	...	...	10 d	0.08 (3.2)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 0.6 mg/L CO_2	...	...	30 d	0.07 (2.6)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 27 mg/L CO_2	...	...	30 d	0.04 (1.5)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 34 mg/L CO_2	...	...	10 d	0.02 (0.8)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 34 mg/L CO_2	...	...	30 d	0.01 (0.3)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 162 mg/L CO_2	...	...	10 d	0.03 (1.0)	...	177
Zinc	Z13001	...	Several grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Distilled water. Plus 162 mg/L CO_2	...	...	30 d	0.01 (0.4)	...	177
Zinc	Z13001	...	Various grades. 99.99% rolled and cast zinc, also with up to 0.1% lead and galvanized steel. No effect due to composition. Plus 0.6 ppm free CO_2. Conductivity water: <1 × 10^{-6} mho	...	...	56 d	0.3 (10)	...	177
Zinc	Z13001	...	Various grades. 99.99% rolled and cast zinc, also with up to 0.1% lead and galvanized steel. No effect due to composition. Conductivity water. Plus 0.8 ppm free CO_2	...	...	56 d	0.3 (10)	...	177
Zinc	Z13001	...	Various grades. 99.99% rolled and cast zinc, also with up to 0.1% lead and galvanized steel. No effect due to composition. Conductivity water. Plus 8.0 ppm free CO_2	...	...	56 d	0.3 (12)	...	177

(Continued)

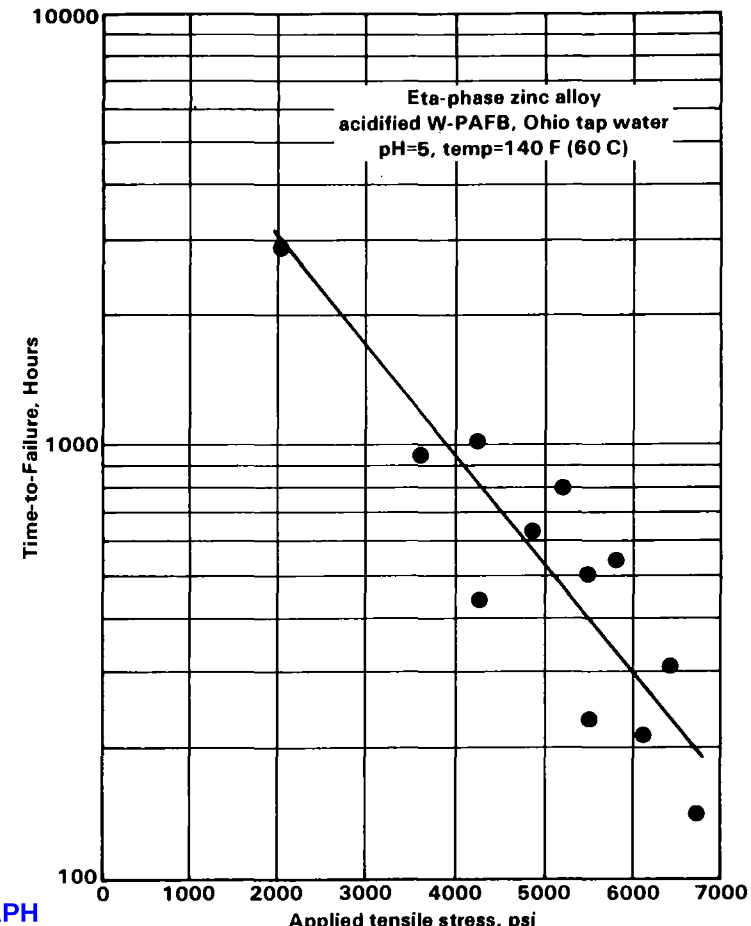
Corrosion Behavior of Various Metals and Alloys in Water (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Zinc	Z13001	...	Various grades. Electrolytic 99.98% zinc and refined zinc containing 1% lead. Conductivity water. Plus 36 ppm free CO_2	...	...	56 d	0.9 (37)	...	177
Zinc, 99.97%	Z13001	Cast	Conductivity 3.8 × 1 × 10^{-6} mho. Distilled water, quiet	...	...	3 d	0.3 (11)	...	177
Zinc, 99.97%	Z13001	Cast	Conductivity 3.8 × 1 × 10^{-6} mho. Distilled water, quiet	...	...	1 d	0.4 (15)	...	177
Zinc, 99.97%	Z13001	Cast	Conductivity 3.8 × 1 × 10^{-6} mho. Distilled water, air bubbled through	...	...	1 d	0.9 (37)	...	177
Zinc, 99.97%	Z13001	Cast	Conductivity water atmosphere free from carbon dioxide	...	...	1 d	0.1 (4.0)	...	177
Zinc, 99.97%	Z13001	Cast	Distilled water, air washed in KOH bubbled through	...	...	1 d	0.1 (6.6)	...	177
Zinc, 99.97%	Z13001	Cast	Distilled water, CO_2 bubbled through	...	...	1 d	0.7 (29)	...	177
Zinc, 99.97%	Z13001	Cast	Distilled water, solution rotated	...	...	1 d	1.0 (39)	...	177
Refractory metals and alloys									
Cobalt	...	...	Static. Distilled	...	25 (77)	...	0.005 (0.2)	...	54
Tantalum	R05210	...	Chlorine saturated	...	25 (76)	...	Resistant	...	42
Ti-3Al-2.5V, grade 9	...	...	Seawater	...	Boiling	...	Resistant	...	91
Titanium	...	...	Chlorine saturated	...	75 (165)	...	0.003 (0.1)	...	27
Titanium	...	Welded	Chlorine saturated	...	88 (190)	...	0.003 (0.1)	...	27
Titanium	...	...	Chlorine saturated	...	97 (207)	...	0.07 (2.8)	...	27
Titanium	...	...	Chlorine saturated	Saturated	97 (207)	...	Resistant	...	90
Titanium	...	...	Degassed	...	316 (601)	...	Resistant	...	90
Titanium	...	...	River. Saturated with Cl	...	93 (200)	...	Resistant	...	90
Titanium	...	...	Seawater	...	Boiling	...	Resistant	...	91
Stainless steels									
301	S30100	...	Tap water	...	20 (68)	...	Resistant	...	253
302	S30200	...	Tap water	...	20 (68)	...	Resistant	...	253
303	S30300	...	Tap water	...	20 (68)	...	Resistant	...	253
304	S30400	...	Tap water	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Tap water	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Tap water	...	20 (68)	...	Resistant	...	253
316	S31600	...	Tap water	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Tap water	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Tap water	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Tap water	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Tap water	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Tap water	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Tap water	...	20 (68)	...	Resistant	...	253
321	S32100	...	Tap water	...	20 (68)	...	Resistant	...	253
329	S32900	...	Tap water	...	20 (68)	...	Resistant	...	253
347	S34700	...	Tap water	...	20 (68)	...	Resistant	...	253
403	S40300	...	Tap water	...	20 (68)	...	Resistant	...	253
405	S40500	...	Tap water	...	20 (68)	...	Resistant	...	253
409	S40900	...	Tap water	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Room	...	Resistant	...	121
410	S41000	...	Mine water	...	Room	...	Resistant	...	121
410	S41000	...	Seawater	...	Room	...	Poor	...	121
410	S41000	...	Tap water	...	20 (68)	...	Resistant	...	253
416	S41600	...	Tap water	...	20 (68)	...	Resistant	...	253
420	S42000	...	Tap water	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Water (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
430	S43000	...	Tap water	...	20 (68)	...	Resistant	...	253
434	S43400	...	Tap water	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Tap water	...	20 (68)	...	Resistant	...	253



LIVE GRAPH
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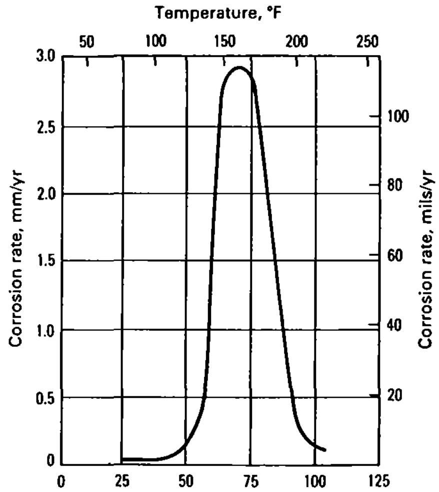
Zinc. Stress vs. time to failure of zinc in tap water. Source: C.J. Slunder and W.K. Boyd, *Zinc: Its Corrosion Resistance*, 2nd ed., T.K. Christman and J. Payer, Ed., International Lead Zinc Research Organization, New York, 1983, 153.



LIVE GRAPH
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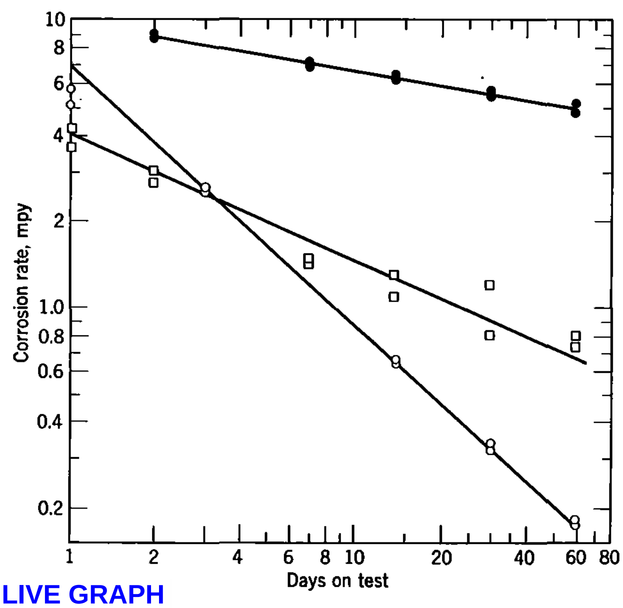
Zinc. Effect of temperature on corrosion of zinc in distilled water. Source: H. Grubitsch and O. Illi, The Hot Water Corrosion of Zinc II, *Korrosion Metall.*, Vol 16, 1940, 197.



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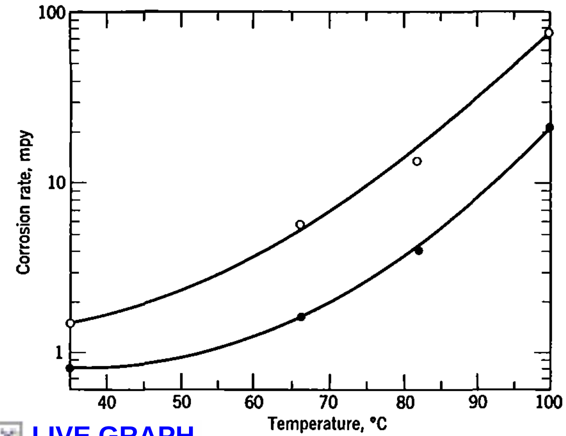
Magnesium. Corrosion rate as a function of time in distilled water (area of solution surface and test coupon surface are about equal). Closed circle: pure magnesium in distilled water vented to air through a caustic trap. Open circle: pure magnesium. Square: AZ92A-T6 alloy in distilled water exposed to atmospheric carbon dioxide. Source: H.P. Godard and M.R. Bothwell, *et al.*, *The Corrosion of Light Metals*, John Wiley & Sons, New York, 1967, 283.



LIVE GRAPH
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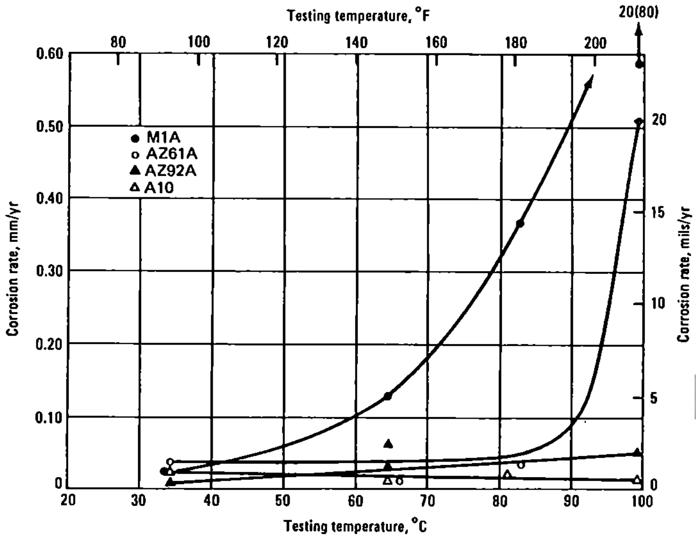
Magnesium. Corrosion rate of magnesium alloys in distilled water as a function of temperature. Circle: M1A alloy. Square: AZ61A alloy. Source: H.P. Godard, M.R. Bothwell, *et al.*, *The Corrosion of Light Metals*, John Wiley & Sons, New York, 1967, 284.

Alloy	Corrosion rate (mpy) 100°C[a]	150°C[b]
Pure magnesium	640	–
Ferrosilicon magnesium		Destroyed
A3A[c]	38	Destroyed
AZ31*B*	17	1200
AZ91	–	1100
AZ92*A*	14	–
HK31*A*	11	–
HZ31*A*	–	440
ZK60*A*	1000	–
M1A	78	2400

[a] 14 days stagnant immersion.
[b] 1.7 to 5.0 days stagnant immersion.
[c] A special-purity magnesium–3% aluminum alloy for nuclear applications.

Magnesium. Corrosion of magnesium alloys in hot deionized water. Source: H.P. Godard, M.R. Bothwell, *et al.*, *The Corrosion of Light Metals*, John Wiley & Sons, New York, 1967, 284.



Magnesium. Effects of temperature on corrosion rates of magnesium alloys M1A, AZ61A, AZ92A, and A10 in tap water. Source: *Metals Handbook*, 9th ed., Vol 2, Properties and Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH, 1979, 602.

LIVE GRAPH
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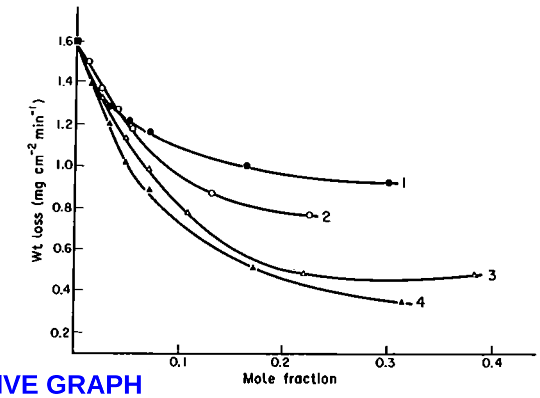

LIVE GRAPH
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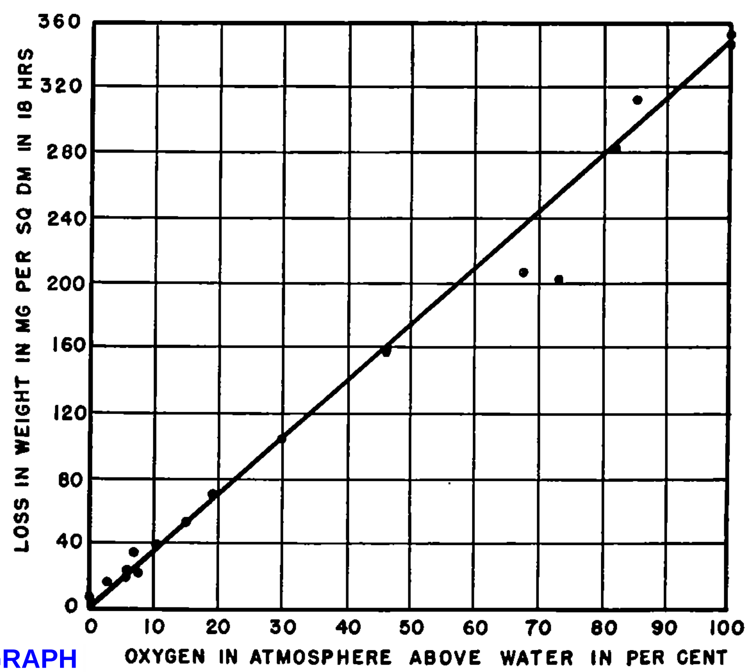
Aluminum. Relationship between the weight loss of aluminum strip in 2*M* water and the mole fraction of the organic solvent in the medium. (1) Water-ethanol, (2) water-isopropanol, (3) water-methanol, (4) water-ethylene glycol. Composition: 99.5Al-0.22Si-0.16Fe. Source: B.A. Abd-El-Nabey, N. Khalil, *et al.*, "The Acid Corrosion of Aluminium in Water-Organic Solvent Mixtures," *Corrosion Science*, Vol 25, 1985, 229.



LIVE GRAPH
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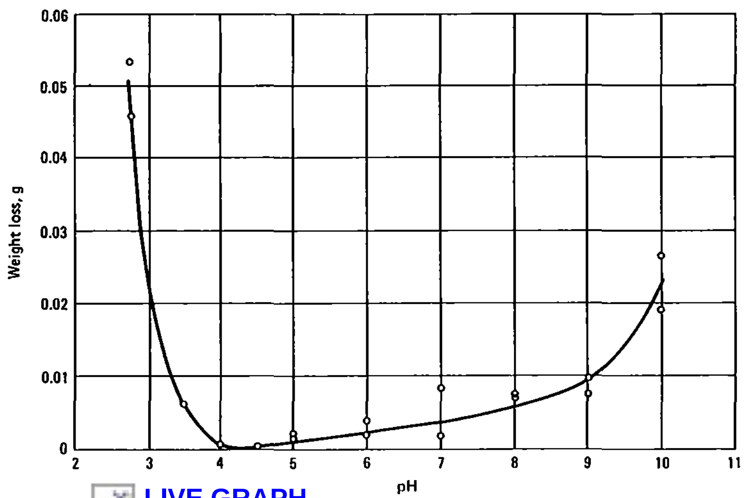
Lead. Effect of oxygen on corrosion of lead submerged in distilled water at 25 °C. Source: G.O. Hiers, "Lead and Lead Alloys," in *The Corrosion Handbook*, H.H. Uhlig, Ed., John Wiley & Sons, New York, 1948, 210.



LIVE GRAPH
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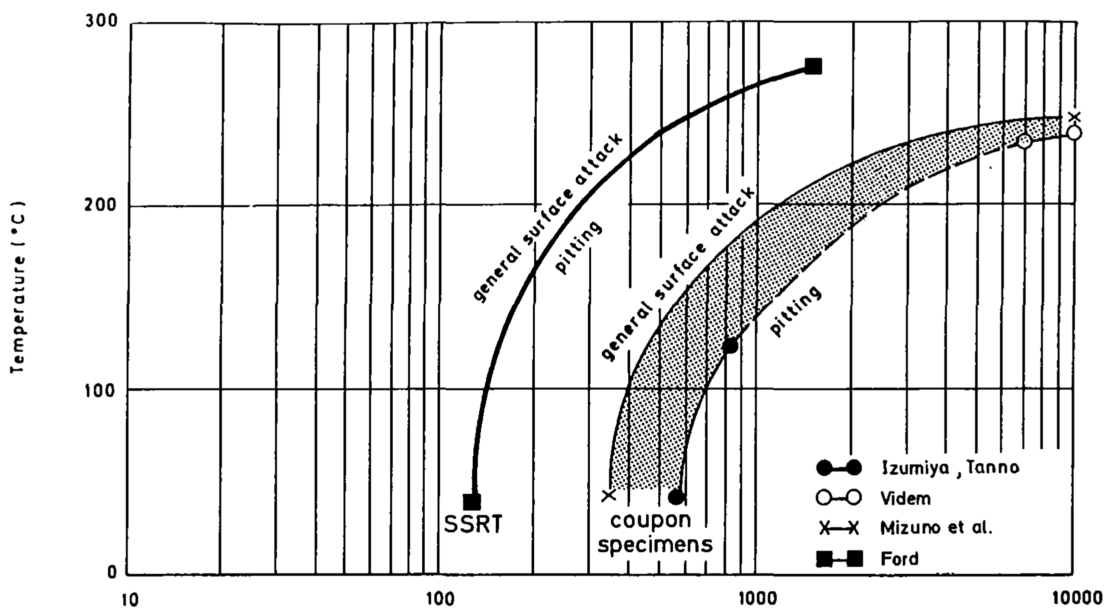
Aluminum. Weight loss of alloy 3004-H14 exposed 1 week in distilled water and in solutions of various pH values. Specimens were 1.6 x 13 x 75 mm (0.06 x 0.5 x 3 in.). The pH values of solutions were adjusted with HCl and NaOH. Test temperature was 60 °C (140 °F). Source: *Metals Handbook*, 9th ed., Vol 2, Properties Selection: Nonferrous Alloys and Pure Metals, American Society for Metals, Metals Park, OH 1979, 205.



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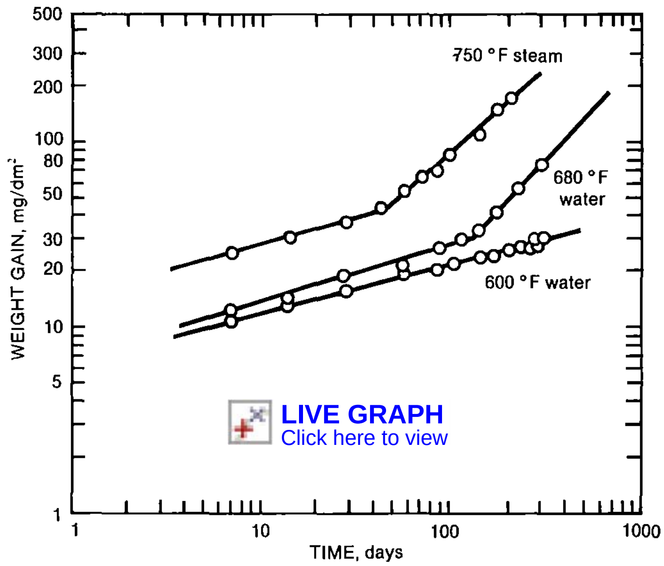
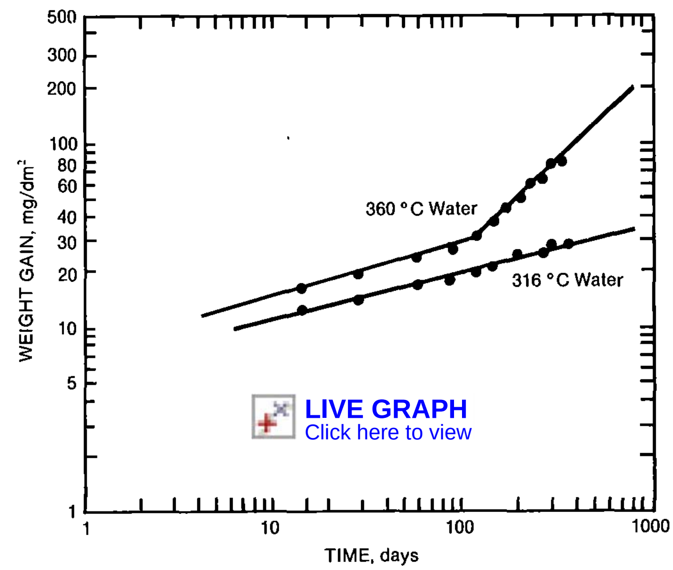
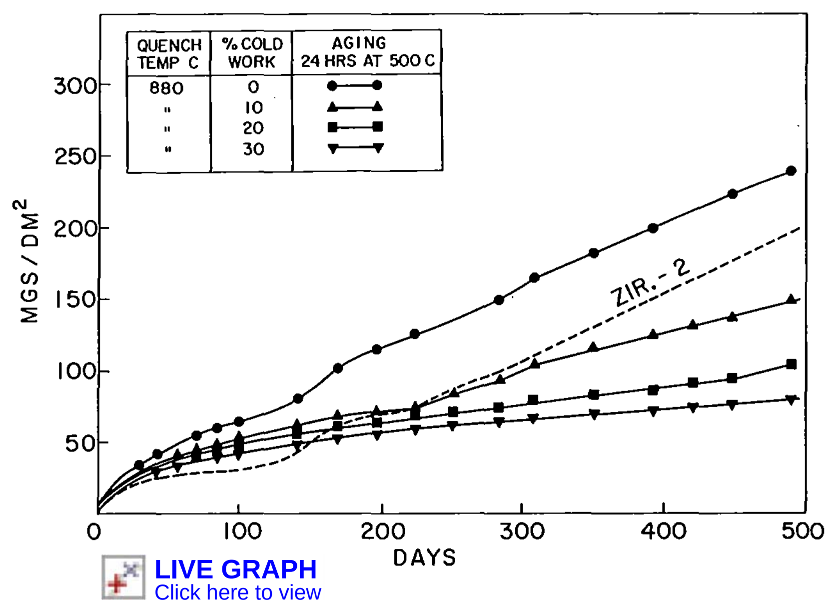
Low-alloy steels. Effect of oxygen content and temperature on pitting of unalloyed and low-alloy steels in stagnant BWR-quality water. Source: J. Hickling, "Strain-Induced Corrosion Cracking of Low-Alloy Steels in LWR Systems: Case Histories and Identification of Conditions Leading to Susceptibility," *Nuclear Engineering and Design*, Vol 91, Feb 1986, 329.



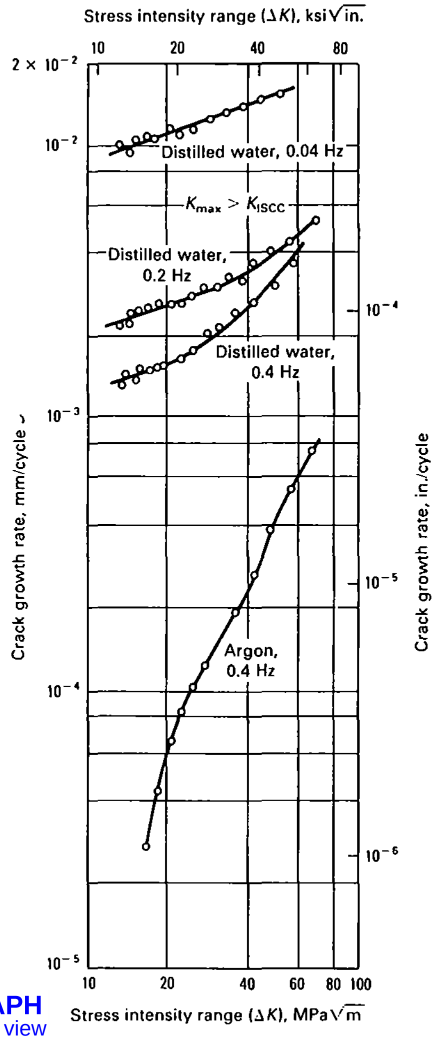
Zirconium. Corrosion behavior of Zircaloy-2 in high-temperature water and steam. Source: Stanley Kass, The Development of the Zircaloys, in *Corrosion of Zirconium Alloys* (STP 368), ASTM, Philadelphia, 1964, 15.



Zirconium. Corrosion behavior of Zircaloy-4 in water. Source: *ASTM Manual on Zirconium and Hafnium* (STP 639), J.H. Schemel, Ed., ASTM, Philadelphia, 1977, 24.



Zirconium. Effect of cold work and aging time on corrosion of 2.5Nb zirconium in water at 360 °C, 2750 psig. Source: J.E. LeSurf, "The Corrosion Behavior of 2.5Nb Zirconium Alloy," in *Applications-Related Phenomena in Zirconium and Zirconium Alloys* (STP 458), ASTM, Philadelphia, 1969, 291.



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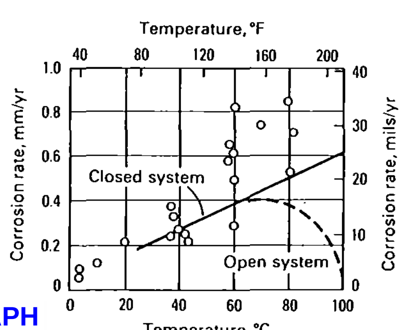
4340 steel. Effect of stress intensity range and loading frequency on corrosion fatigue crack growth in ultrahigh-strength 4340 steel exposed to distilled water at 23 °C (73 °F). Source: C.S. Kortovich, Corrosion Fatigue of 4340 and D6AC Steels Below K_{ISCC}, in *Proceedings of the 1974 Triservice Conference on Corrosion of Military Equipment*, AFML-TR-75-42, Air Force Materials Laboratory, Wright-Patterson Air Force Base, 1975.



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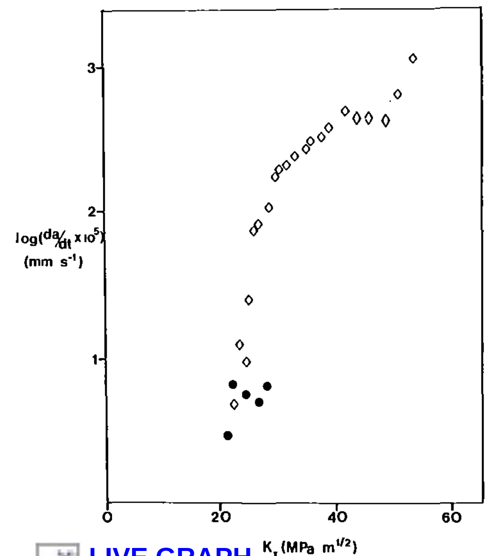
Steel. Effect of temperature on corrosion of steel in water. Data points are from actual plant measurements of corrosion under insulation. Source: *Metals Handbook*, 9th ed., Vol 13, Corrosion, ASM International, Metals Park, OH, 1987, 1145.



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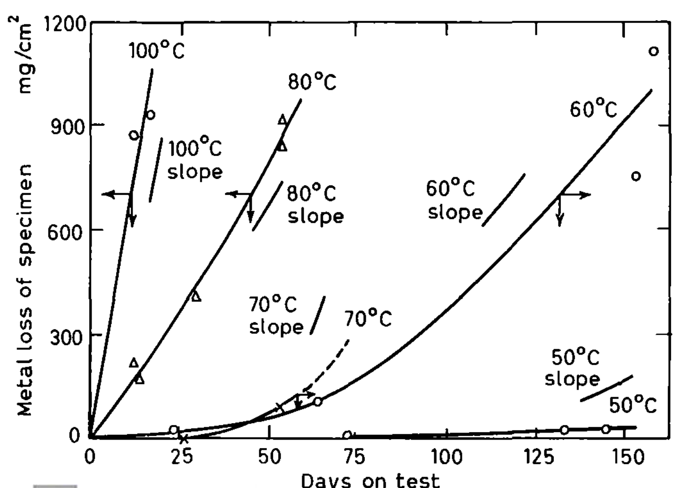
Stainless steel. Variation in crack velocity with the stress intensity factor for En56C (AISI 420) martensitic stainless steel tempered at 400 °C. Tested in water (diamond) and in NACE solution (closed circle). Source: C.J. Thomas, R.G.J. Edyvean, *et al.*, "Environmentally Assisted Crack Growth in a Martensitic Stainless Steel," *Materials Science and Engineering*, Vol 78, Feb 1986, 58.

GASEOUS AND AQUEOUS CORROSION



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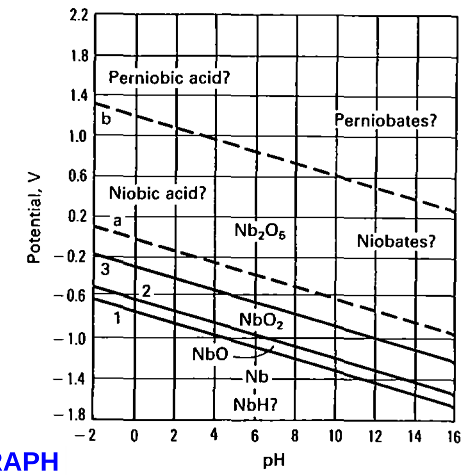
Uranium. Corrosion of standard uranium in aerated distilled water. Source: J.H. Gittus, *Uranium*, Butterworths, Washington, 1963, 406.



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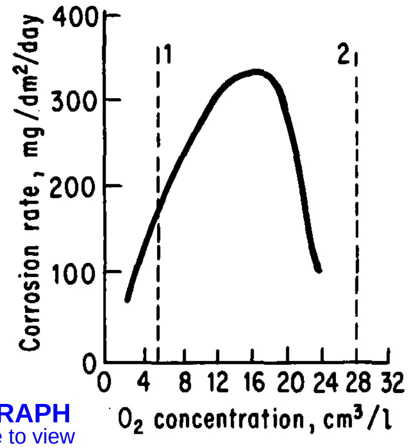
Niobium. Pourbaix (potential-pH) diagram for niobium in water at 25 °C (75 °F). Source: M. Pourbaix, *Atlas of Electrochemical Equilibria in Aqueous Solutions*, Pergamon Press, New York, 1966.



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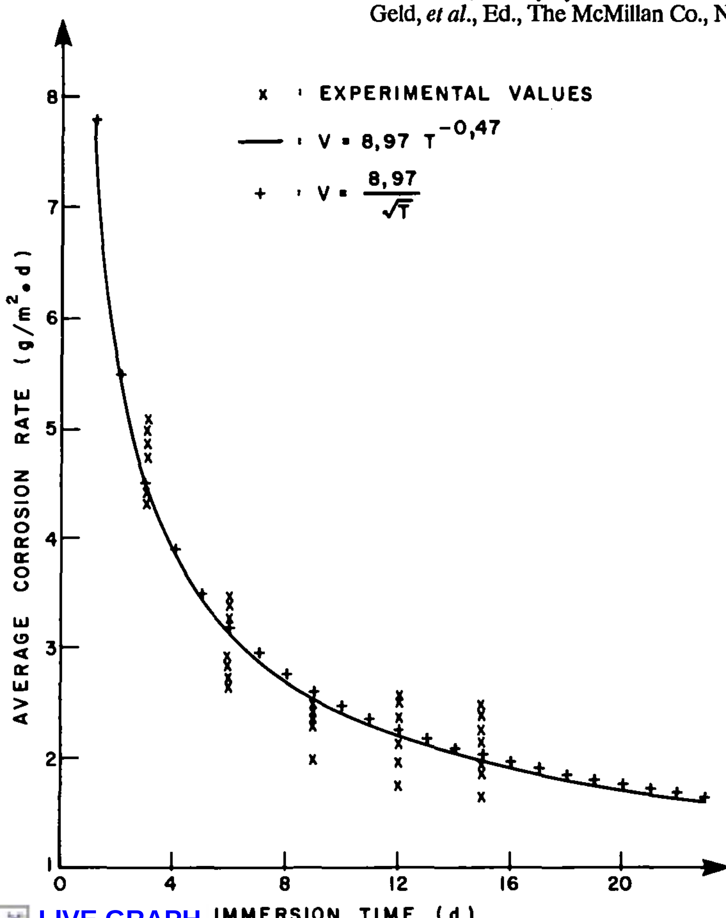
Iron. Effect of oxygen concentration in distilled water (pH 7) on the corrosion rate of iron at 25 °C. The dashed lines show the oxygen content of water upon contact with air (1) and with pure oxygen (2). Source: N.D. Tomashov, *Theory of Corrosion and Protection of Metals*, B. Tytell, I. Geld, *et al.*, Ed., The McMillan Co., New York, 1966, 505.



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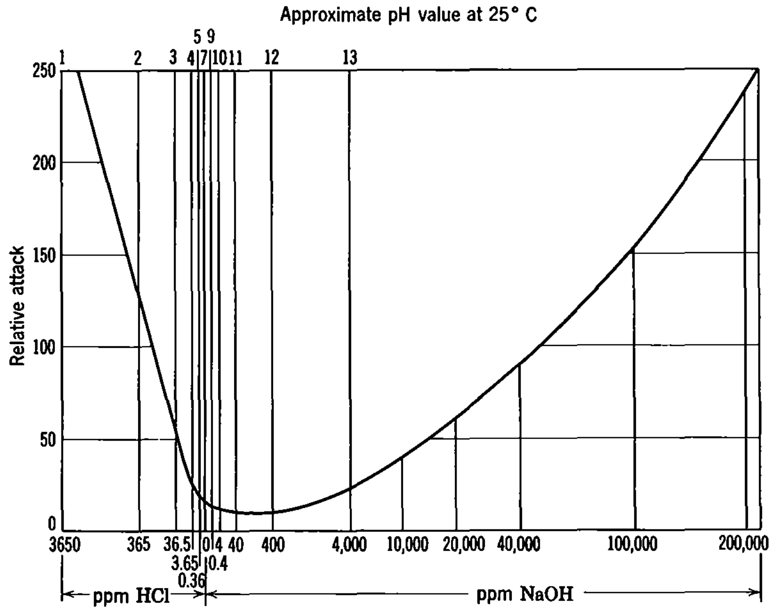
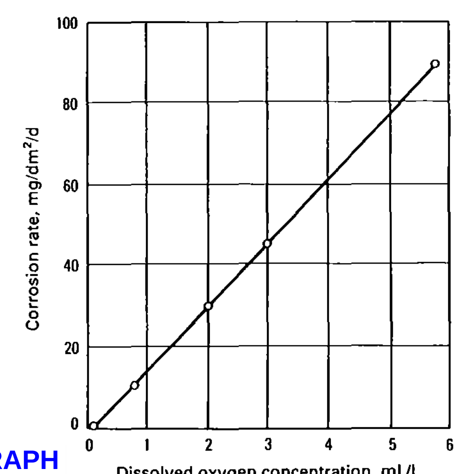
Cast iron. Average corrosion rate of cast iron as a function of immersion time and in the presence of chlorides and nitrates. (Cl^-) = 157 mg/L; (NO_3^-) = 199.0 mg/L. Source: D.L. Piron and R. Desjardins, "Corrosion Rate of Cast Iron and Copper Pipe by Drinking Water," in *Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods* (STP 908), G.C. Moran and P. Labine, Ed., ASTM, Philadelphia, 1986, 364.



Iron. Corrosion of iron by water at 310 °C (590 °F) at various pH values measured at 25 °C. Source: H.H. Uhlig and R.W. Revie, *Corrosion and Corrosion Engineering: An Introduction to Corrosion Science and Engineering*, 3rd ed., John Wiley & Sons, New York, 1985.



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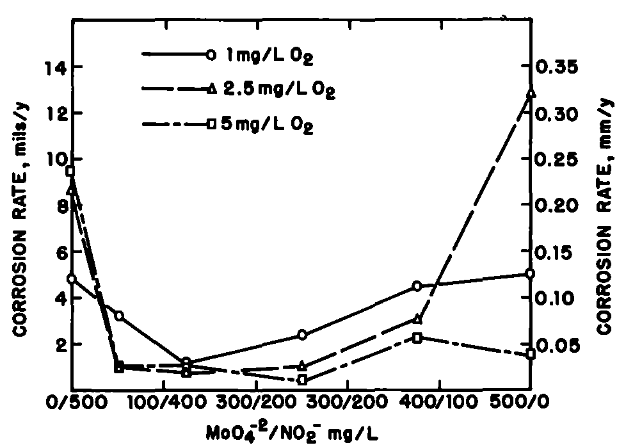
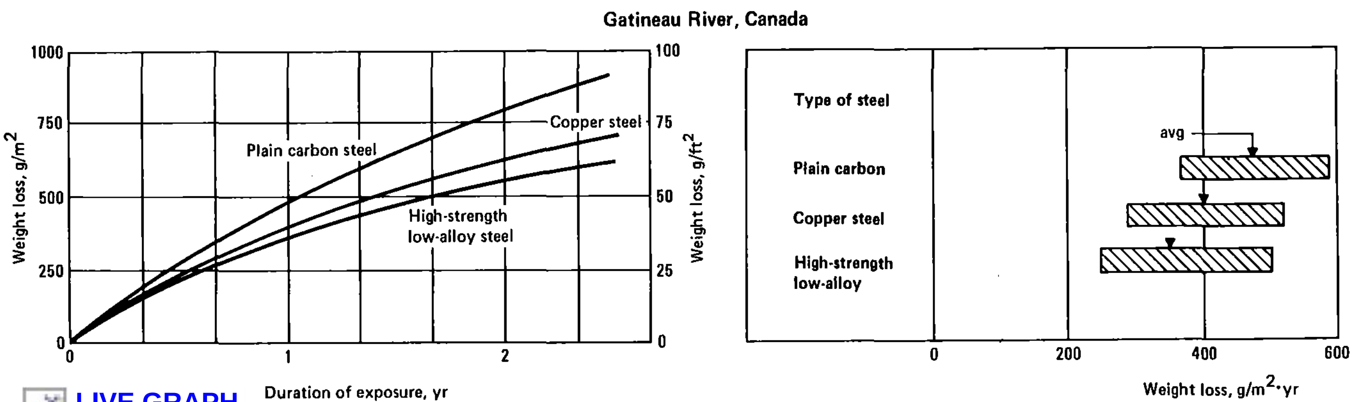
Low-carbon steel. Effect of oxygen concentration on the corrosion of low-carbon steel in slowly moving water containing 165 ppm calcium chloride. The 48-h test was conducted at 25 °C (75 °F). Source: H.H. Uhlig and R.W. Revie, *Corrosion and Corrosion Control*, 3rd ed., Wiley Interscience, New York, 1985, 108.



Carbon steel. Corrosion rate of SAE 1010 steel in 60 °C test water of pH 9 inhibited with MoO_4^{-2}/NO_2^- combinations in the presence of 0, 1, 2.5, and 5 mg/L oxygen. Source: T.R. Weber, M.A. Stranick, *et al.*, "Molybdate Corrosion Inhibition in Deaerated and Low-Oxygen Waters," *Corrosion*, Vol 42, Sept 1986, 543.



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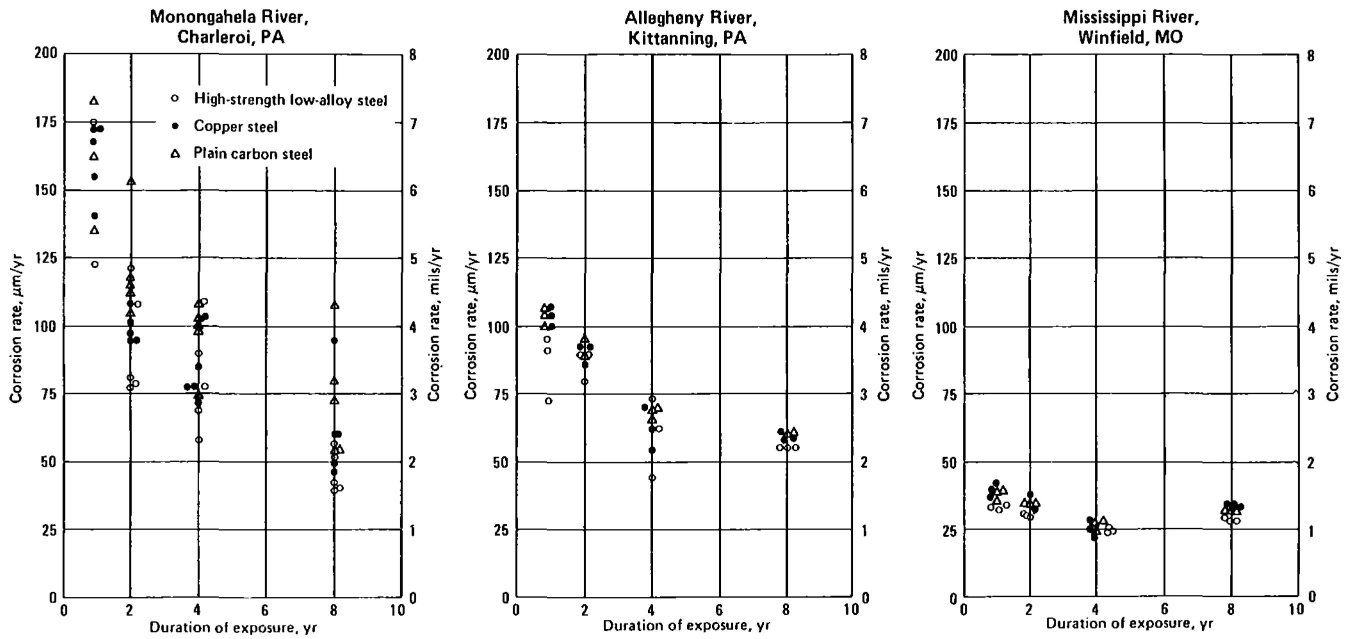

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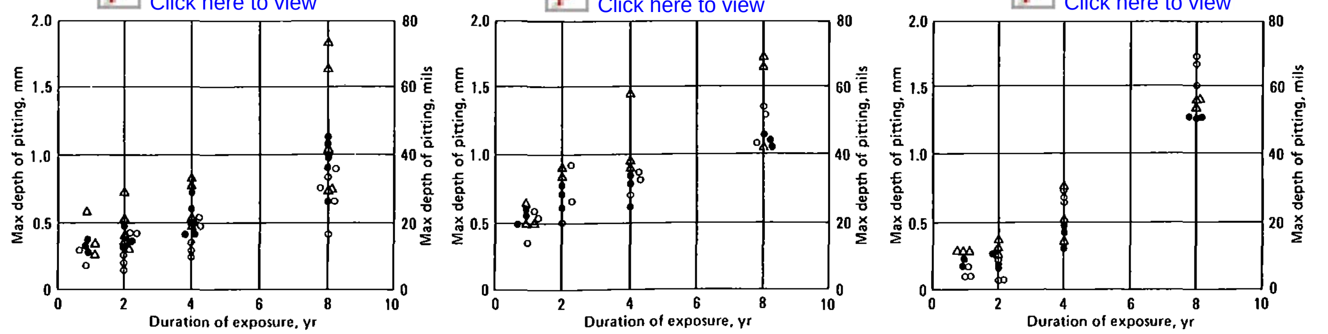
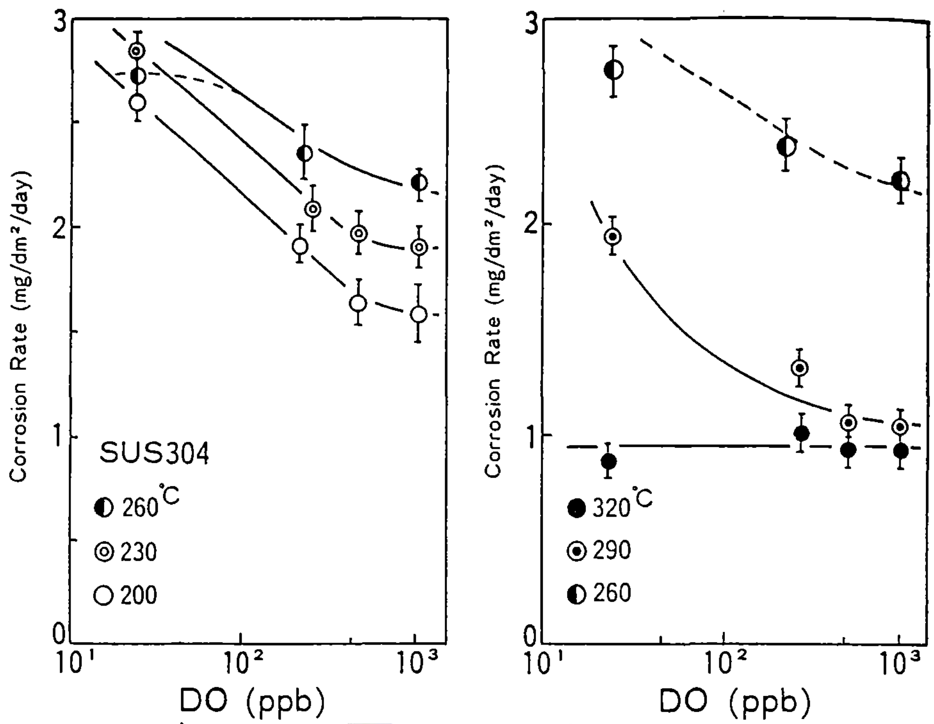


Low-carbon steel. Corrosion of three types of low-carbon steel in four rivers. Source: *Metals Handbook*, 9th ed., Vol 1, Properties and Selection: Irons and Steels, American Society for Metals, Metals Park, OH, 1978, 737.



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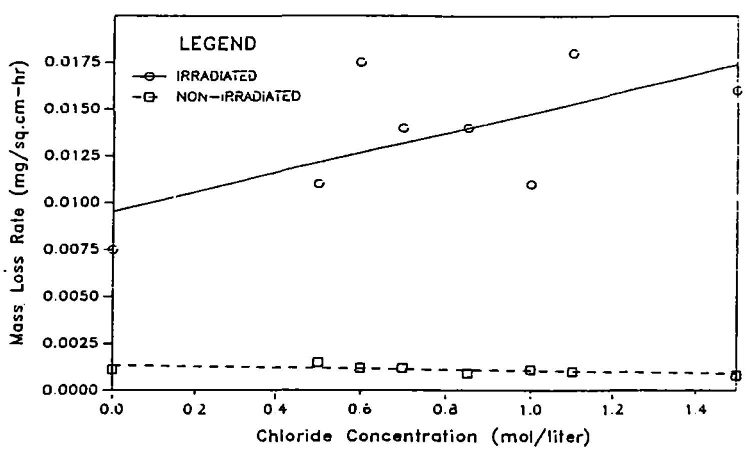
Stainless steel. Corrosion rate dependency on dissolved oxygen concentration. Ref. 259



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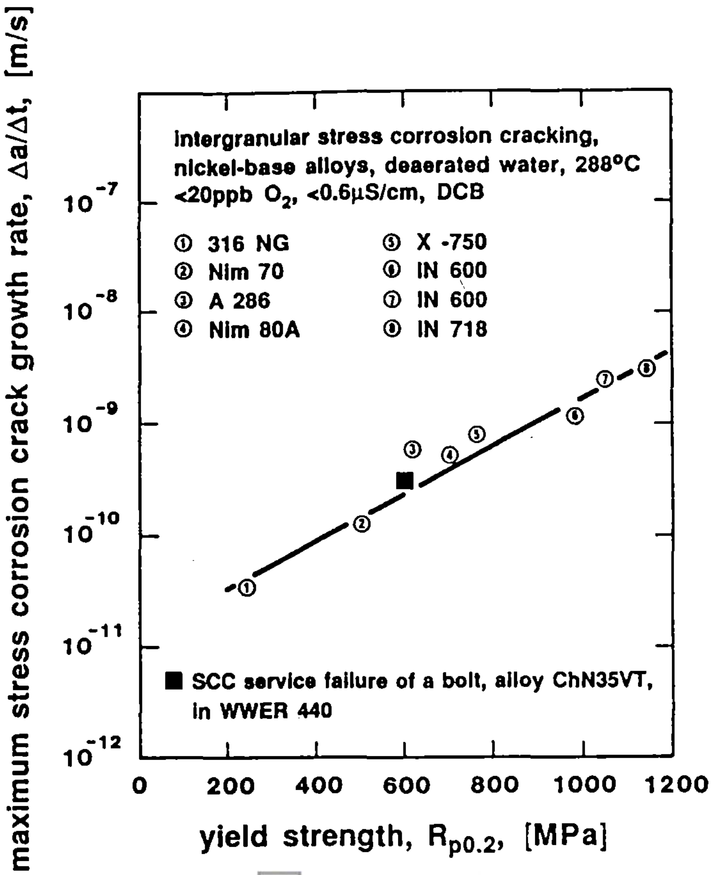
Carbon steel. Corrosion rate of AISI 1018 steel at –25 °C as a function of chloride concentration. Ref. 262



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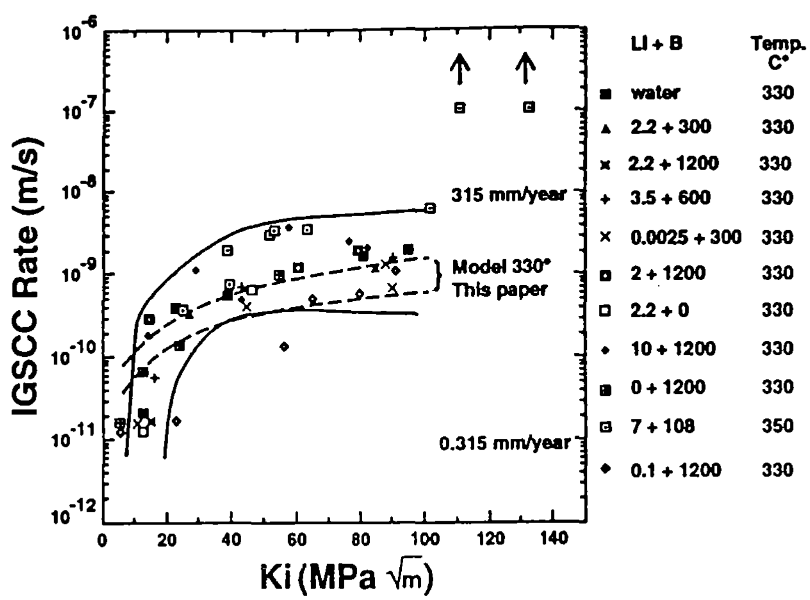
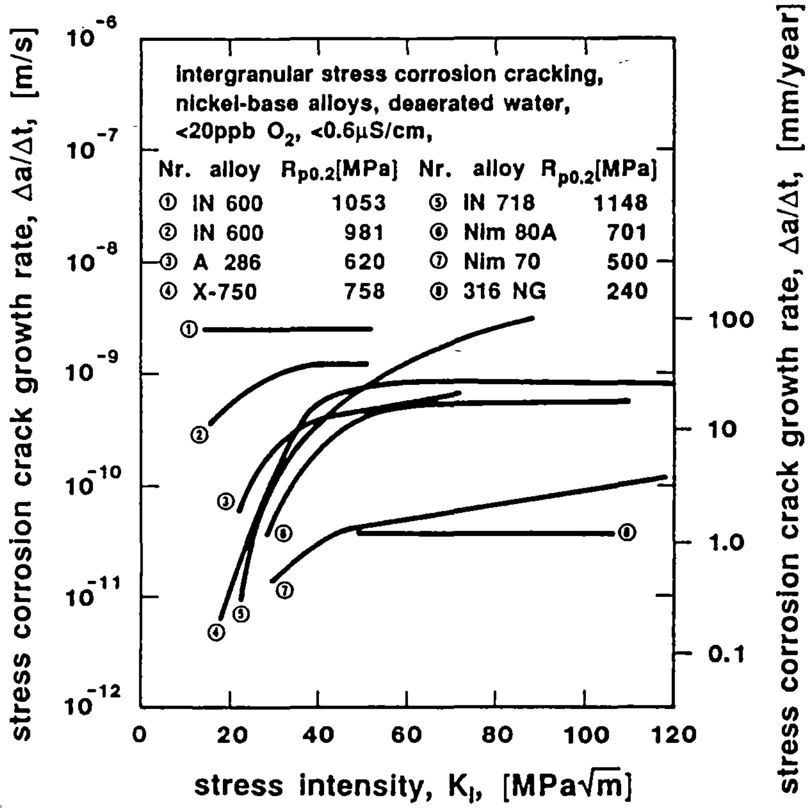
Nickel-base alloys. Maximum stress corrosion crack growth rates plotted versus yield strength. For comparison, a growth rate associated with an actual SCC service failure in a nuclear power plant in high purity water.



Nickel alloy. Average crack growth rates as a function of the stress intensity factor for Alloy 600 in high purity water.



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Various alloys. Comparison of crack growth rate curves in high purity water.

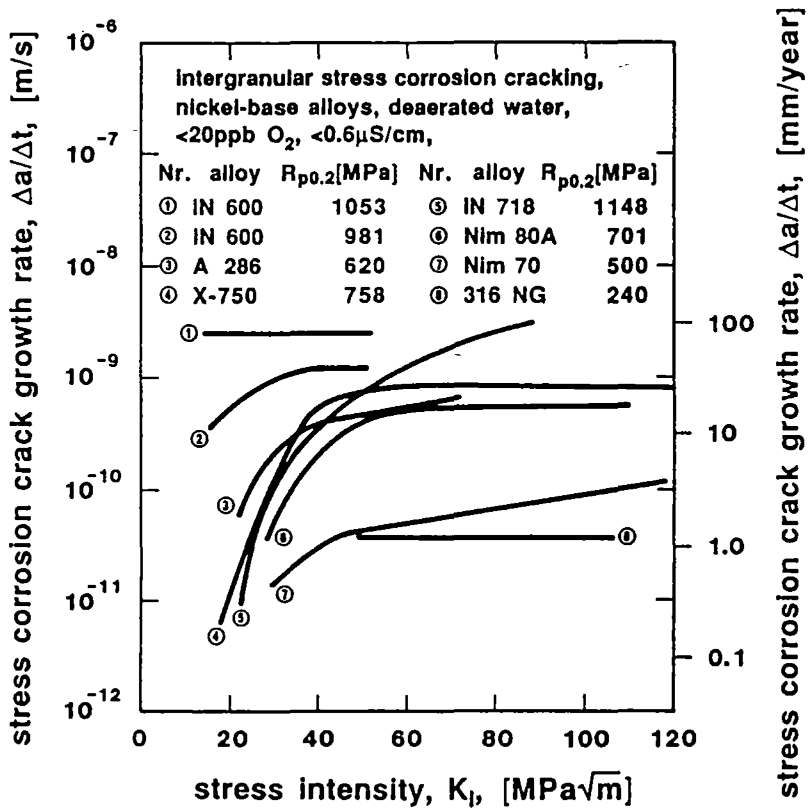
Xylene

Also known as dimethylbenzene, $C_6H_4(CH_3)_2$ is an isomeric mixture of o- m-, and p-xylene. It is a clear liquid with various grades having different boiling points, that is insoluble in water and soluble in alcohol and ether, and used in aviation gasoline, coatings, lacquers, rubber cements, organic synthesis, and polyester resin manufacture.

Corrosion Behavior of Various Metals and Alloys in Xylene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253

(Continued)



Various alloys. Comparison of crack growth rate curves in high purity water.

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Corrosion Behavior of Various Metals and Alloys in Xylene

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	...	253
301	S30100	...	...	...	Boiling	...	Resistant	...	253
302	S30200	...	...	...	20 (68)	...	Resistant	...	253
302	S30200	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Xylene (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
303	S30300	...	...	...	Boiling	...	Resistant	...	253
303	S30300	...	...	...	20 (68)	...	Resistant	...	253
303	S30300	...	...	...	Boiling	...	Resistant	...	253
304	S30400	...	...	...	20 (68)	...	Resistant	...	253
304	S30400	...	...	...	Boiling	...	Resistant	...	253
304L	S30403	...	...	...	20 (68)	...	Resistant	...	253
304L	S30403	...	...	...	Boiling	...	Resistant	...	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	...	Boiling	...	Resistant	...	253
316	S31600	...	...	...	20 (68)	...	Resistant	...	253
316	S31600	...	...	...	Boiling	...	Resistant	...	253
316F	S31620	...	...	...	20 (68)	...	Resistant	...	253
316F	S31620	...	...	...	Boiling	...	Resistant	...	253
316L	S31603	...	...	...	20 (68)	...	Resistant	...	253
316L	S31603	...	...	...	Boiling	...	Resistant	...	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	...	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	...	Boiling	...	Resistant	...	253
317L	S31703	...	...	...	20 (68)	...	Resistant	...	253
317L	S31703	...	...	...	Boiling	...	Resistant	...	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	...	Boiling	...	Resistant	...	253
321	S32100	...	...	...	20 (68)	...	Resistant	...	253
321	S32100	...	...	...	Boiling	...	Resistant	...	253
329	S32900	...	...	...	20 (68)	...	Resistant	...	253
329	S32900	...	...	...	Boiling	...	Resistant	...	253
347	S34700	...	...	...	20 (68)	...	Resistant	...	253
347	S34700	...	...	...	Boiling	...	Resistant	...	253
403	S40300	...	...	...	20 (68)	...	Resistant	...	253
403	S40300	...	...	...	Boiling	...	Resistant	...	253
405	S40500	...	...	...	20 (68)	...	Resistant	...	253
405	S40500	...	...	...	Boiling	...	Resistant	...	253
409	S40900	...	...	...	20 (68)	...	Resistant	...	253
409	S40900	...	...	...	Boiling	...	Resistant	...	253
410	S41000	...	...	...	20 (68)	...	Resistant	...	253
410	S41000	...	...	...	Boiling	...	Resistant	...	253
416	S41600	...	...	...	20 (68)	...	Resistant	...	253
416	S41600	...	...	...	Boiling	...	Resistant	...	253
420	S42000	...	...	...	20 (68)	...	Resistant	...	253
420	S42000	...	...	...	Boiling	...	Resistant	...	253
430	S43000	...	...	...	20 (68)	...	Resistant	...	253
430	S43000	...	...	...	Boiling	...	Resistant	...	253
434	S43400	...	...	...	20 (68)	...	Resistant	...	253
434	S43400	...	...	...	Boiling	...	Resistant	...	253
F51	S31803	...	...	...	20 (68)	...	Resistant	...	253
F51	S31803	...	...	...	Boiling	...	Resistant	...	253

Zinc Chloride

Zinc chloride, $ZnCl_2$, is soluble in water and alcohol and melts at 290 °C. It is used as a catalyst and in electroplating, wood preservation, textile processing, petroleum refining, medicine and feed additives.

Corrosion Behavior of Various Metals and Alloys in Zinc Chloride

Material	UNS	Condition	Comments	Concen-tration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Refractory metals and alloys									
Titanium, grade 12	R53400	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 16	...	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 18	...	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Titanium, grade 2	R50400	...	Tight crevices pH 3	Saturated	Boiling	...	Poor	...	215
Titanium, grade 7	R52400	...	Tight crevices pH 3	Saturated	Boiling	...	Resistant	...	215
Stainless steels									
301	S30100	...	...	...	20 (68)	...	Resistant	Pitting	253
301	S30100	...	...	...	45 (113)	...	Questionable	Pitting	253
301	S30100	...	...	...	Boiling	...	Poor	Pitting	253
302	S30200	...	...	...	20 (68)	...	Resistant	Pitting	253
302	S30200	...	...	...	45 (113)	...	Questionable	Pitting	253
302	S30200	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	20 (68)	...	Good	Pitting	253
303	S30300	...	...	...	20 (68)	...	Resistant	Pitting	253
303	S30300	...	...	...	45 (113)	...	Questionable	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
303	S30300	...	...	...	Boiling	...	Poor	Pitting	253
304	S30400	...	...	...	20 (68)	...	Resistant	Pitting	253
304	S30400	...	...	...	45 (113)	...	Questionable	Pitting	253
304	S30400	...	...	...	Boiling	...	Poor	Pitting	253
304L	S30403	...	...	...	20 (68)	...	Resistant	Pitting	253
304L	S30403	...	...	...	45 (113)	...	Questionable	Pitting	253
304L	S30403	...	...	...	Boiling	...	Poor	Pitting	253
304LN	S30453	...	...	...	20 (68)	...	Resistant	Pitting	253
304LN	S30453	...	...	...	45 (113)	...	Questionable	Pitting	253
304LN	S30453	...	...	...	Boiling	...	Poor	Pitting	253
316	S31600	...	...	...	20 (68)	...	Resistant	Pitting	253
316	S31600	...	...	...	45 (113)	...	Good	Pitting	253
316	S31600	...	...	...	Boiling	...	Questionable	Pitting	253
316F	S31620	...	...	...	20 (68)	...	Resistant	Pitting	253
316F	S31620	...	...	...	45 (113)	...	Questionable	Pitting	253
316F	S31620	...	...	...	Boiling	...	Poor	Pitting	253
316L	S31603	...	...	...	20 (68)	...	Resistant	Pitting	253
316L	S31603	...	...	...	45 (113)	...	Good	Pitting	253
316L	S31603	...	...	...	Boiling	...	Questionable	Pitting	253
316LN	S31653	...	...	...	20 (68)	...	Resistant	Pitting	253
316LN	S31653	...	...	...	45 (113)	...	Good	Pitting	253
316LN	S31653	...	...	...	Boiling	...	Questionable	Pitting	253
316Ti	S31635	...	...	...	20 (68)	...	Resistant	Pitting	253
316Ti	S31635	...	...	...	45 (113)	...	Good	Pitting	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Zinc Chloride (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
316Ti	S31635	...	...	...	Boiling	...	Questionable	Pitting	253
317L	S31703	...	...	...	20 (68)	...	Resistant	Pitting	253
317L	S31703	...	...	...	45 (113)	...	Good	Pitting	253
317L	S31703	...	...	...	Boiling	...	Questionable	Pitting	253
317LN	S31725	...	...	...	20 (68)	...	Resistant	Pitting	253
317LN	S31725	...	...	...	45 (113)	...	Good	Pitting	253
317LN	S31725	...	...	...	Boiling	...	Questionable	Pitting	253
321	S32100	...	...	...	20 (68)	...	Resistant	Pitting	253
321	S32100	...	...	...	45 (113)	...	Questionable	Pitting	253
321	S32100	...	...	...	Boiling	...	Poor	Pitting	253
329	S32900	...	...	...	20 (68)	...	Resistant	Pitting	253
329	S32900	...	...	...	45 (113)	...	Good	Pitting	253
329	S32900	...	...	...	Boiling	...	Questionable	Pitting	253
347	S34700	...	...	...	20 (68)	...	Resistant	Pitting	253
347	S34700	...	...	...	45 (113)	...	Questionable	Pitting	253
347	S34700	...	...	...	Boiling	...	Poor	Pitting	253
403	S40300	...	...	...	20 (68)	...	Good	Pitting	253
403	S40300	...	...	...	Boiling	...	Poor	Pitting	253
405	S40500	...	...	...	20 (68)	...	Good	Pitting	253
405	S40500	...	...	...	Boiling	...	Poor	Pitting	253
409	S40900	...	...	...	20 (68)	...	Good	Pitting	253
409	S40900	...	...	...	Boiling	...	Poor	Pitting	253
410	S41000	...	...	...	20 (68)	...	Good	Pitting	253
410	S41000	...	...	...	Boiling	...	Poor	Pitting	253
416	S41600	...	...	...	20 (68)	...	Good	Pitting	253
416	S41600	...	...	...	Boiling	...	Poor	Pitting	253
420	S42000	...	...	...	20 (68)	...	Good	Pitting	253
420	S42000	...	...	...	Boiling	...	Poor	Pitting	253
430	S43000	...	...	...	20 (68)	...	Good	Pitting	253
430	S43000	...	...	...	Boiling	...	Poor	Pitting	253
434	S43400	...	...	...	20 (68)	...	Good	Pitting	253
434	S43400	...	...	...	Boiling	...	Poor	Pitting	253
F51	S31803	...	...	...	20 (68)	...	Resistant	Pitting	253
F51	S31803	...	...	...	45 (113)	...	Good	Pitting	253
F51	S31803	...	...	...	Boiling	...	Questionable	Pitting	253

Zinc Cyanide

Zinc cyanide, $Zn(CN)_2$, is toxic, colorless, rhombic crystals, insoluble in water and alcohol, and is used in metal plating and as a chemical reagent and insecticide.

Corrosion Behavior of Various Metals and Alloys in Zinc Cyanide

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	Moist	...	20 (68)	...	Resistant	...	253
302	S30200	...	Moist	...	20 (68)	...	Resistant	...	253
303	S30300	...	Moist	...	20 (68)	...	Good	...	253
303	S30300	...	Moist	...	20 (68)	...	Resistant	...	253
304	S30400	...	Moist	...	20 (68)	...	Resistant	...	253
304L	S30403	...	Moist	...	20 (68)	...	Resistant	...	253
304LN	S30453	...	Moist	...	20 (68)	...	Resistant	...	253
316	S31600	...	Moist	...	20 (68)	...	Resistant	...	253
316F	S31620	...	Moist	...	20 (68)	...	Resistant	...	253
316L	S31603	...	Moist	...	20 (68)	...	Resistant	...	253
316LN	S31653	...	Moist	...	20 (68)	...	Resistant	...	253
316Ti	S31635	...	Moist	...	20 (68)	...	Resistant	...	253
317L	S31703	...	Moist	...	20 (68)	...	Resistant	...	253
317LN	S31725	...	Moist	...	20 (68)	...	Resistant	...	253
321	S32100	...	Moist	...	20 (68)	...	Resistant	...	253
329	S32900	...	Moist	...	20 (68)	...	Resistant	...	253
347	S34700	...	Moist	...	20 (68)	...	Resistant	...	253
403	S40300	...	Moist	...	20 (68)	...	Good	...	253
405	S40500	...	Moist	...	20 (68)	...	Good	...	253
409	S40900	...	Moist	...	20 (68)	...	Good	...	253
410	S41000	...	Moist	...	20 (68)	...	Good	...	253
416	S41600	...	Moist	...	20 (68)	...	Good	...	253
420	S42000	...	Moist	...	20 (68)	...	Good	...	253
430	S43000	...	Moist	...	20 (68)	...	Good	...	253
434	S43400	...	Moist	...	20 (68)	...	Resistant	...	253
F51	S31803	...	Moist	...	20 (68)	...	Resistant	...	253

Zinc Sulfate

Also known as zinc vitriol, $ZnSO_4$ is rhombic crystals; is readily soluble in water but loses water to the air or on heating to 100 °C (280 °F). Used to obtain electrolyte zinc, in printing textiles and to make lithopone, to impregnate wood and hides, as an additive to spinning baths for production of synthetic silks, in electroplating, and in animal feeds.

Corrosion Behavior of Various Metals and Alloys in Zinc Sulfate

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
Stainless steels									
301	S30100	...	...	Saturated	20 (68)	...	Resistant	...	253
301	S30100	...	...	Saturated	Boiling	...	Resistant	...	253
302	S30200	...	...	Saturated	20 (68)	...	Resistant	...	253
302	S30200	...	...	Saturated	Boiling	...	Resistant	...	253
303	S30300	...	...	Saturated	20 (68)	...	Resistant	...	253
303	S30300	...	...	Saturated	Boiling	...	Resistant	...	253
304	S30400	...	...	Saturated	20 (68)	...	Resistant	...	253

(Continued)

Corrosion Behavior of Various Metals and Alloys in Zinc Sulfate (Continued)

Material	UNS	Condition	Comments	Concentration, %	Temperature °C (°F)	Duration	Corrosion rate, mm/yr (mils/yr)	Localized Attack	Reference
304	S30400	...	...	Saturated	Boiling	...	Resistant	...	253
304L	S30403	...	...	Saturated	20 (68)	...	Resistant	...	253
304L	S30403	...	...	Saturated	Boiling	...	Resistant	...	253
304LN	S30453	...	...	Saturated	20 (68)	...	Resistant	...	253
304LN	S30453	...	...	Saturated	Boiling	...	Resistant	...	253
316	S31600	...	...	Saturated	20 (68)	...	Resistant	...	253
316	S31600	...	...	Saturated	Boiling	...	Resistant	...	253
316F	S31620	...	...	Saturated	20 (68)	...	Resistant	...	253
316F	S31620	...	...	Saturated	Boiling	...	Resistant	...	253
316L	S31603	...	...	Saturated	20 (68)	...	Resistant	...	253
316L	S31603	...	...	Saturated	Boiling	...	Resistant	...	253
316LN	S31653	...	...	Saturated	20 (68)	...	Resistant	...	253
316LN	S31653	...	...	Saturated	Boiling	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	20 (68)	...	Resistant	...	253
316Ti	S31635	...	...	Saturated	Boiling	...	Resistant	...	253
317L	S31703	...	...	Saturated	20 (68)	...	Resistant	...	253
317L	S31703	...	...	Saturated	Boiling	...	Resistant	...	253
317LN	S31725	...	...	Saturated	20 (68)	...	Resistant	...	253
317LN	S31725	...	...	Saturated	Boiling	...	Resistant	...	253
321	S32100	...	...	Saturated	20 (68)	...	Resistant	...	253
321	S32100	...	...	Saturated	Boiling	...	Resistant	...	253
329	S32900	...	...	Saturated	20 (68)	...	Resistant	...	253
329	S32900	...	...	Saturated	Boiling	...	Resistant	...	253
347	S34700	...	...	Saturated	20 (68)	...	Resistant	...	253
347	S34700	...	...	Saturated	Boiling	...	Resistant	...	253
403	S40300	...	...	Saturated	Boiling	...	Questionable	...	253
405	S40500	...	...	Saturated	Boiling	...	Questionable	...	253
409	S40900	...	...	Saturated	Boiling	...	Questionable	...	253
410	S41000	...	...	Saturated	Boiling	...	Questionable	...	253
416	S41600	...	...	Saturated	Boiling	...	Questionable	...	253
420	S42000	...	...	Saturated	Boiling	...	Questionable	...	253
430	S43000	...	...	Saturated	Boiling	...	Questionable	...	253
434	S43400	...	...	Saturated	Boiling	...	Resistant	...	253
F51	S31803	...	...	Saturated	20 (68)	...	Resistant	...	253
F51	S31803	...	...	Saturated	Boiling	...	Resistant	...	253